BEHAVIOR OF SOME DISTINCT METALLIC MATERIALS DURING THE ELECTROCHEMICAL MACHINING WITH FORCED HYDRODYNAMIC DEPASSIVATION

Geo Caracaş[1], Laurenţiu Slătineanu[2], Oana Dodun[3], Margareta Coteaţă[4], Irina Beşliu[5]
[1] “Gheorghe Asachi” Technical University of Iași Romania, caracasgeo@gmail.com
[2] “Gheorghe Asachi” Technical University of Iași Romania, slati@tcm.tuiasi.ro
[3] “Gheorghe Asachi” Technical University of Iași Romania, oanadodun@tcm.tuiasi.ro
[4] “Gheorghe Asachi” Technical University of Iași Romania, mcoteata@tcm.tuiasi.ro
[5]Irina Beşliu, “Ştefan cel Mare” University of Suceava, Romania, irina.besliu@yahoo.com

ABSTRACT: The electrochemical machining with forced hydrodynamic depassivation allows the material removal from workpiece by electrochemical erosion. The products resulted as a consequence of the electrochemical reactions developed between the workpiece material and electrolyte are removed from the machining zone by forced circulation of the electrolyte. A theoretical analysis led to formulation of several hypothesis concerning the behaviour of some metallic materials when test samples presenting a conical surface are affected by the electrochemical machining process with forced hydrodynamic depassivation. In the paper, the results of some experimental researches developed on test samples from steel, bronze and aluminium are presented. By mathematical processing of the experimental results, some empirical mathematical models were established. The empirical models highlight the influence exerted by the gap size, by the size of angle corresponding to the conical surface and by the voltage applied to the two electrodes on the size of the final gap and on the quantity of material removed from the test piece, for a certain duration of the machining process.

KEYWORDS: electrochemical machining, hydrodynamic depassivation, experimental research, empirical mathematical models, gap size, material removal rate

1. INTRODUCTION

Electrochemical machining is a machining technique which supposes a process of changing electrical charges and mass among anode, cathode and electrolyte. The workpiece is connected to one of the poles of a direct current supply. If one considers the phenomena which develop on the workpiece surface, two categories of technics could be mentioned;

- Machining techniques by electrochemical erosion, where there is a material removal from workpiece;

- Machining techniques width material addition, when electrochemical deposition of a material layer is achieved.

In the case of *electrochemical erosion*, both the workpiece and the tool electrode are introduced in electrolyte [1, 2, 8].

The workpiece is connected to the positive pole of a direct current supply which could offer a voltage of about 6-20 V and currents of high values (10 – 50000 A). The tool electrode is connected to the negative pole of the same direct current supply. The evolution of the electrolyses process determines the dissolution of a quantity of workpiece material in the electrolyte, as a consequence of the electrical field existing between workpiece and tool electrode.

The performances of the electrochemical erosion are not influenced by the hardness of the material affected by the machining process; thus, the machining method could be applied inclusively in the case of hard and very hard metallic materials, which could not be machined by the so-called classical machining methods (cutting, stamping, plastic deformation etc.). The unique condition is

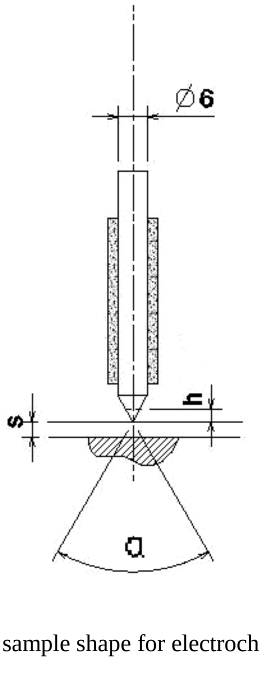

Figure 1. Test sample shape for electrochemical machining

that the workpiece material is electroconductive. The electrochemical machining is also very efficient when parts with complex configurations must be obtained or the deburring must be applied to workpieces obtained previously by classical machining methods.

In the case of electrochemical machining by using the erosion, the parameters of technological interest (output parameters) could be: diminishing of the height of asperities resulted by applying previous roughing machining methods; the material removal rate (the volume of material removed by electrochemical dissolution from the workpiece in a pre-established time); the machining accuracy, which depends on the working conditions; the degree of electrolyte purity, needing a continuous filtering, in order to remove the substances resulted as a consequence of the machining process; the eventual deterioration of the tool electrode, which is not affected by a wear process, but an oxidation process could affect the intensity of the machining technique [3, 5, 6, 7].

As input factors able to influence the sizes of output parameters, one can consider the type and the chemical composition of the workpiece material, the chemical composition and some physical properties of the tool electrode material, the geometrical shape and the position of the tool electrode in relation to the workpiece position, the work movement (in this case, the relative movement of diminishing the distance between the workpiece and tool electrode is considered as main movement), the electrolyte temperature (maintaining of this temperature at an imposed value or within a certain temperature interval could be necessary), the parameters of the electric current circulating between the two electrodes (voltage, current intensity, eventual pulse work, inclusively by changing the polarity, in order to remove the passivating layer, the circulation of the electrolyte in the work gap, in the case of forced hydrodynamic depassivation, in a single direction or in many directions, eventually by changing inclusively the flow direction; the size of the work gap, which could be set by considering the material removal rate or other technological parameters etc.

Taking into consideration the above mentioned aspects, the present paper describes the influence of some input factors on the values of some parameters

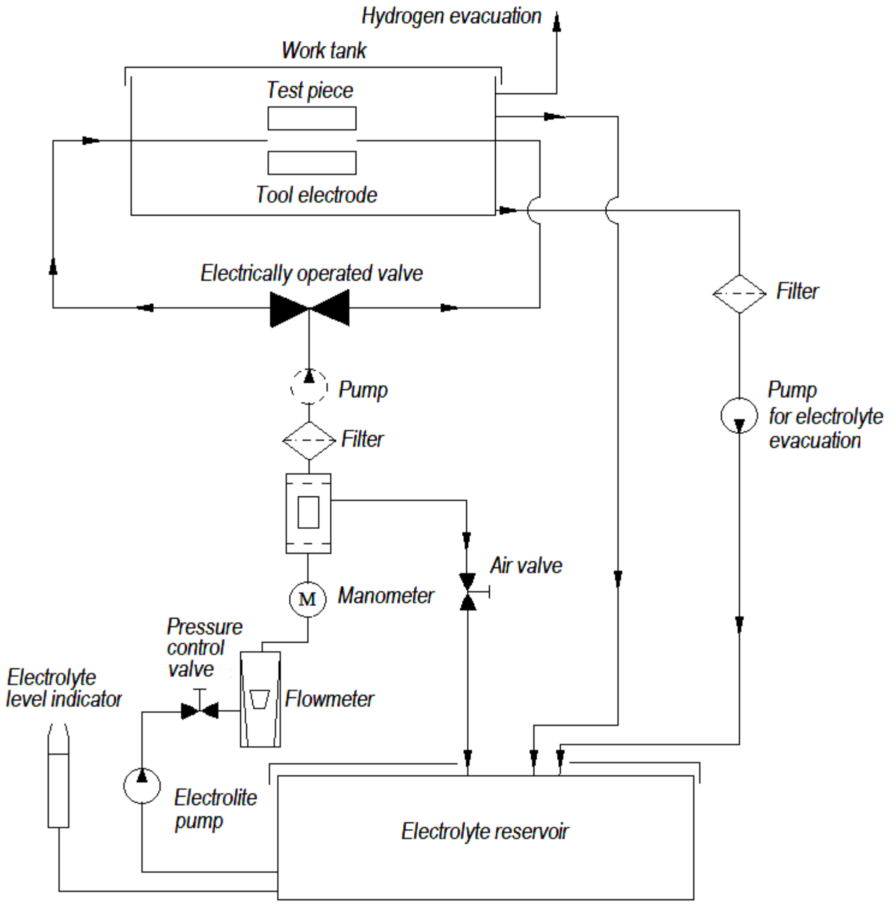

Figure 2.

Figure 3. Hydraulic scheme of equipment for electrochemical machining with forced hydrodynamic depassivation

of technological interest (gap work or the quantity of material removed from workpiece.

2. CONDITIONS SPECIFIQUE TO THE ELECTROCHEMICAL EROSION WITH FORCED HYDRODYNAMICAL DEPASSIVATION

The generation of the passivating layer during the machining process by electrochemical erosion is considered as a not convenient phenomenon, able to affect the efficient development of the machining process. As a result of this situation, the problem of avoiding or diminishing the passivating layer thickness or avoiding the polarization of the electrolyte concentration was formulated. One of the methods aiming the removal of the passivating layer is the forced hydrodynamic depassivation. The method supposes the forced circulation of the electrolyte in the work gap, at a pressure p=7-28 daN/cm^2; this determines the braking and removal of the passivating layer. Adequate pumps must be included in the hydraulic circuit (fig. 1), in order to ensure the necessary high pressure.

In order to study the influence of distinct factors on the sizes of some output parameters of technological interest, an experimental research was designed and achieved. The test samples had the shape showed in figure 2 and they were made of distinct materials (brass, aluminium, steels).

One can remark that the shape of the workpiece active zone was conical, in order to better observe the evolution of the material removal process.

As parameters of technological interest, one can mention the linear size of test piece electrode length diminishing over the process time and the mass of the material removed from workpiece. The mass was determined by means of an analytical balance. The mass of the test piece was determined before and after applying the process of material removal from test piece by electrochemical machining process.

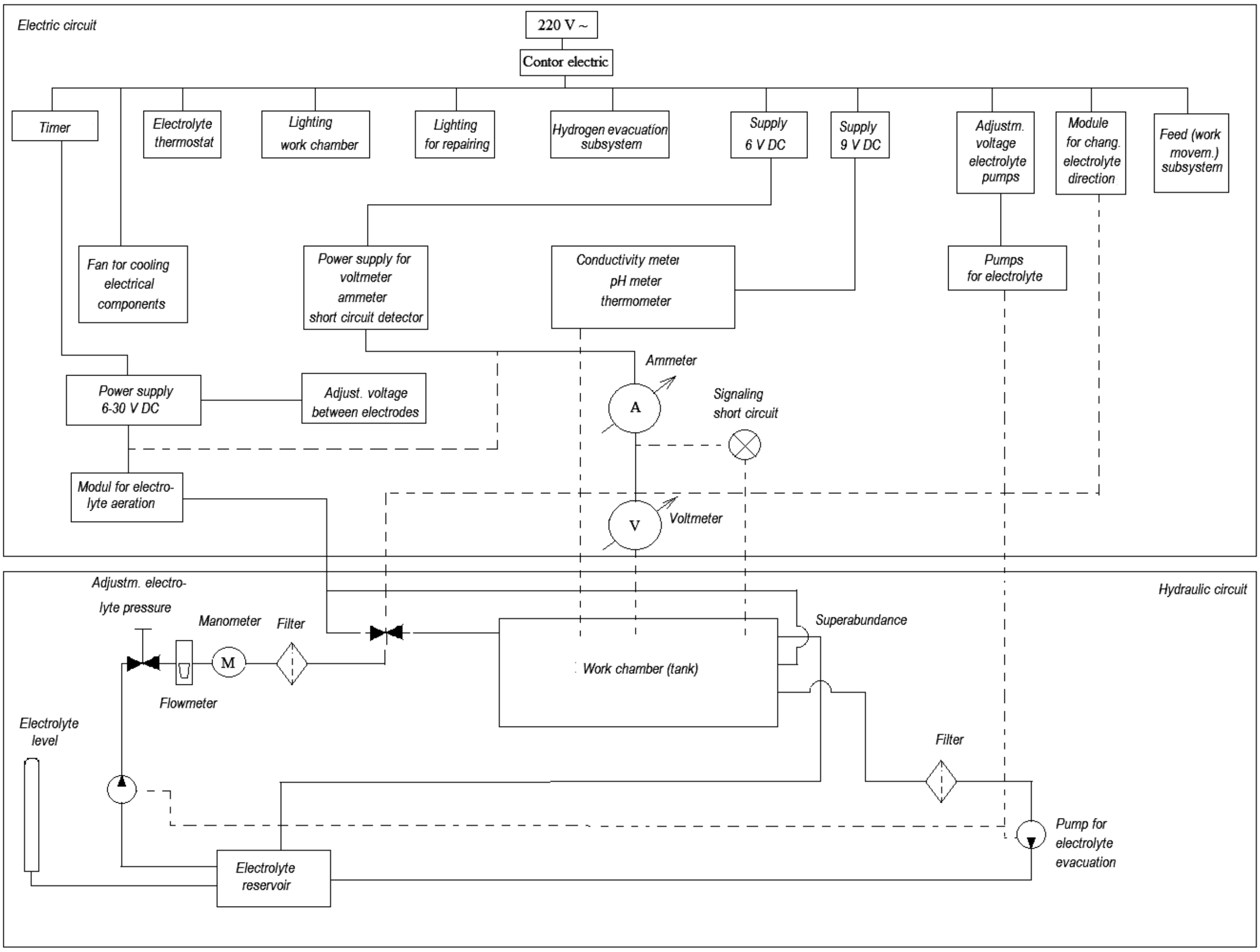

Figure 4. Block scheme of equipment for electrochemical machining

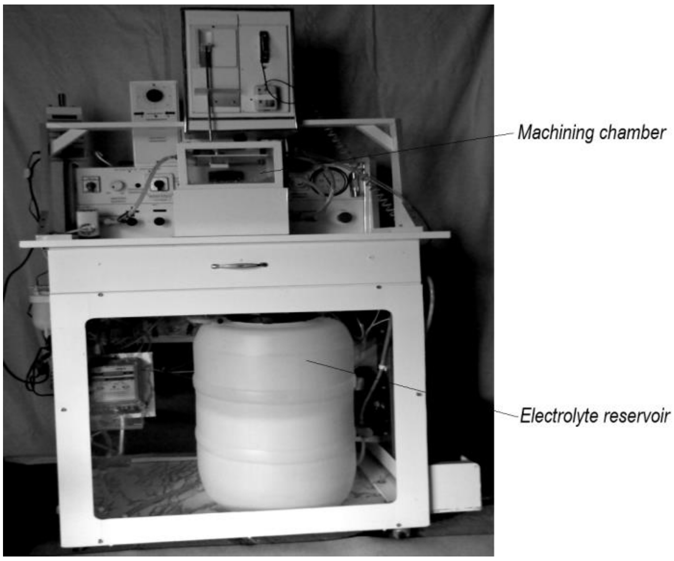

Figure 5. Equipment for experimental study of the gap evolution during the electrochemical machining process

As above mentioned, during the electrochemical sun machining process, due to the phenomenon of electrolyte concentration polarization, on the workpiece surface a layer with more and more reduced electrical conductivity or just an insulating layer is generated and, thus, a passivating film appears. In order to ensure the continuity of the machining process, the passivating film must be removed. This request is met by acting on the pressure and flow speed of the electrolyte in the work gap, so that the desired results are obtained.

One must mention that during the electrochemical machining process, disturbing factors could generate negative and uncontrolled effects; such factors are the inhomogeneity of the workpiece material, the uncontrolled variation of the parameters characterizing the work conditions etc. If it is not possible to avoid the influence of such factors, the minimization of their effects could be taken into consideration.

3. EXPERIMENTAL CONDITIONS

In order to highlight the influence exerted by some input factors acting during the electrochemical machining process on the sizes of some parameters of technological interest, an equipment able to materialize the electrochemical machining process was designed and achieved. The principle schema of this equipment is presented in figure 3, while in figure 4 an image of the equipment could be observed.

As a material for tool electrode, the copper was used. Three distinct materials (carbon steel, brass and aluminium) were used as materials for test samples. The electrolyte was an aqueous solution of sodium chloride (20%). A thermostatic subsystem was included in equipment, in order to maintain a temperature of about 25 ^{o} C.

The research objective was to investigate the influence exerted by some process input factors on the evolution of the machining process, estimated by the distance h between the test sample and the cathode. As process input factors, the angle α of test sample cone, the voltage U applied to the two electrodes and the value s_0 of the initial work gap were used. The test duration was of 3 minutes.

4. EXPERIMENTAL RESULTS AND THEIR PROCESSING

The experimental results were used in order to establish an empirical mathematical model, able to characterize the evolution of the electrochemical machining process in the above mentioned experimental conditions. Since it is expected a monotone variation of the process output parameter s for the variation interval of the process input factors, as empirical mathematical model, the power type function was preferred:

$$s = C\alpha^x s_0^y U^z, \qquad (1)$$

where s is the size of the gap after a process duration of 3 minutes, α – the initial angle of the test sample cone (degrees), U – voltage applied to the two electrodes (V), C is a constant and x, y, z are exponents whose values could be established by mathematical processing of the experimental results.

One considered also that due to the monotone variation of the parameter s, only two levels of the process input factors could be used.

The coefficients and the exponents corresponding to the power functions could be determined by using graphical representations, but at present, the simultaneous influence exerted by many input factors on the output parameter could be more precisely estimated by using the method of factorial experiments and the method of the least squares. For the three independent variables and two experimental levels, a set of 8 experiments is necessary to be made. Adequate software facilitates the operative determination of the empirical functions corresponding to the process investigated [4].

In the case of the experimental research presented in this paper, the following values were used for the process input factors: α_{min}=60 ^{o} and α_{max}=120 ^{o}, U_{min}=12 V and U_{max}=20 V, s_{0min}=0.1 mm and s_{0max}=0.3 mm.

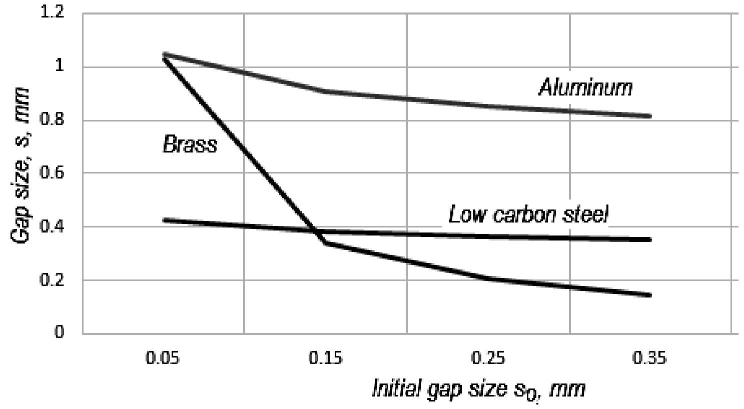

Figure 7. Influence of the initial gap size s_0 on the final gap size *s*, after a machining duration of 3 minutes, in the case of three distinct materials (electrolyte: aqueous solution 20 %, NaCl, α=60 º, *U*=12 V)

By mathematical processing of the experimental results, the following empirical power type functions were determined:

- In the case of low carbon steel:

$s=1.627*10^{-2}*\alpha^{-0.386}*s_0^{-0.905}*U^{1.838}$; (2)

- In the case of bras:

$s=6.872*10^{-2}*\alpha^{-0.598}*s_0^{-1.008}*U^{0.859}$; (3)

- In the case of test samples made of aluminium:

$s=0.231*\alpha^{-0.325}*s_0^{-0.128}*U^{0.989}$. (4)

On the base of the empirical functions defined by the relations (2), (3) and (4), the graphical representations from figure 5 and 6 were elaborated.

The analysis of the power type functions corresponding to the three tested materials showed that in the case of low carbon steel, the most important factor from the point of view of its influence on the final gap size *s* is the voltage *U*, whose exponent has the maximum value (*z*=1.838); the statement is valid also in the case of aluminium, when the exponent has the value *z*=0.989. In the case of brass, the maximum influence is exerted by the size of the initial gap s_0, whose exponent has the value *y*=-1.808.

As expected, the increase of the initial gap size s_0 determines the diminishing of the final gap size *s*, while the increase of the voltage *U* applied to the electrodes has an effect of increasing the size *s* of the final machining gap.

One could also notice that in the case of all tested materials, the increase of the angle corresponding to the test sample cone determines a decrease of the final gap *s*, since the exponent *x* has negative values for all the test samples materials.

In the diagram from figure 6, one can observe that the decrease of the final gap size *s* is more intense in the case of test samples made of aluminium and brass and less intense in the case when the low carbon steel was the material for test samples. Among the tested material, the aluminium was characterized by a higher value of the final machining gap *s*, while the low carbon steel proved a lower decrease of the work gap size.

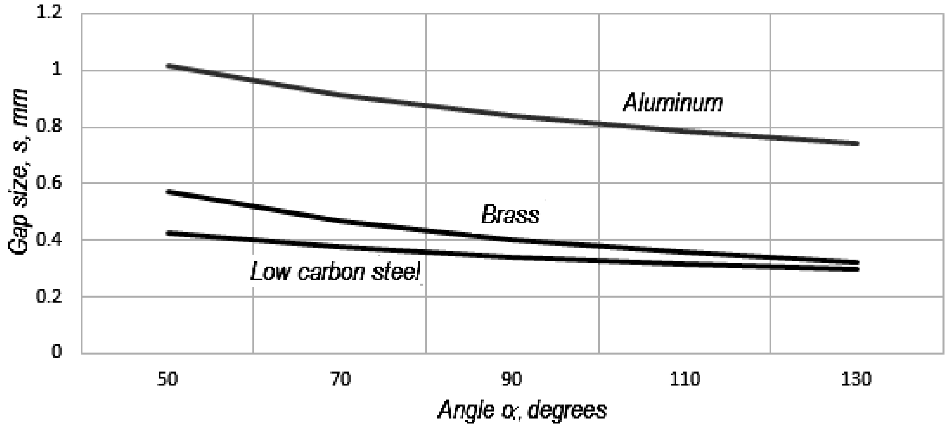

Figure 6. Influence of the angle α of the test sample cone on the final gap size *s*, after a machining process duration of 3 minutes, in the case of three distinct materials (electrolyte: aqueous solution 20 % NaCl, s_0=0.1 mm, *U*=12 V)

5. CONCUSIONS

The electrochemical machining is based on the material removal process when the tool electrode and workpiece are immersed in an electrolyte solution and the both electrodes are connected in the circuit of a direct current supply. There are many factors able to exert influence on the parameters of technological interest (material removal rate, roughness and accuracy of the machined surfaces, machining gap evolution etc.). In order to investigate the influence exerted by some process input factors, an equipment able to facilitate the study of the gap size evolution was designed and achieved. A factorial experiment with three independent variables (initial gap size, angle of the test sample cone and the voltage applied to the two electrodes at two levels was used, taking into consideration a monotone variation of the output parameter in relation to the variation of the process input factors. A software based on the method of least square was used, in order to establish the mathematical empirical models. One considered that power type functions could offer a direct and operative image concerning the influence of the considered process input factors on the final gap size. The experimental results showed that the test sample made of aluminium were more intense affected by the material removal process, while the test samples made of low carbon steel proved a less intense material removal process. A stronger influence is exerted by the size of the initial work gap s0 and by the voltage U applied to electrodes. In the future, there is the intention to extend the experimental research, taking into consideration other test samples materials and other shapes of the test samples active zones.

6. REFERENCES (HEADING 1)

1. Bâlc, N., *Nonconventional technologies* (in Romanian), Dacia Publishing House, Cluj-Napoca, Romania, (2001).
2. Brusilovski, S., Adjustment and readjustment of electrochemical machines and control of the process parameters in machining shaped surfaces, *Journal of Materials Processing Technology*, Vol. 196, No. 1, 311–320, (2008).
3. Coteaţă, M., Slătineanu, L., Dodun, O., Nagîţ, G., Study on electrochemical machining process. Proceedings of the conference *“Modern technologies, quality, restructuring 2003”*, Vol. 2, Technical University of Moldova from Chişinău, Republic of Moldova, pp. 45-47, (2003).
4. Creţu, G., *Fundamentals of experimental research. Laboratory handbook* (in Romanian), “Gheorghe Asachi” Technical University of Iaşi, (1992).
5. Klocke, F., Zeis, M., Harst, S., Klink, A., D. Veselovac, D., Baumgärtner, M., Modeling and Simulation of the Electrochemical Machining (ECM) Material Removal Process for the Manufacture of Aero Engine Components, *14th CIRP Conference on Modeling of Machining Operations (CIRP CMMO),* Procedia CIRP 8, pp. 265 – 270, (2013)
6. Kurita, T., Chikamori, K., Kubota, S., Hattori, M., A study of three-dimensional shape machining with an ECμM system, *International Journal of Machine Tools & Manufacture*, Vol. 46, No. 12-13, pp. 1311–1318, (2006).
7. Schulze, H.P., Schatzing, W., Influences of different contaminations on the electro-erosive and the electrochemical micro-machining, *The Seventeenth CIRP Conference on Electro Physical and Chemical Machining (ISEM),* Procedia CIRP 6, pp. 58 – 63, (2013).
8. Slătineanu, L., Nagîţ, G., Dodun, O., Coteaţă, M., Chinesta, F., Gonçalves-Coelho, A., Pamies Teixeira J., San Juan, M., Santo, L., Santos, F. *Non-traditional manufacturing processes,* Tehnica Info Publishing House, Chişinău, Republic of Moldova, (2004).