PREMISES OF IDENTIFYING EQUIPMENT FOR CUTTING BY ELECTROCHEMICAL MACHINING

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ABSTRACT: The study of residual stresses in metal parts can be performed by making slits where such stresses are assumed to exist. Measuring the width of the slits can provide information on the type and size of residual stresses. The slits must be made by machining processes that do not introduce other stresses in the part's material. One of the methods that can be used in this regard is electrochemical cutting. In the paper, the ideas diagram method was used to analyze the possibilities of contouring some alternatives for the different components of electrochemical cutting equipment. An equipment structure was designed to allow the realization of slits in metal parts to evaluate the internal stresses in parts made of metal.
KEYWORDS: internal stresses, electrochemical cutting, idea diagram method, equipment design, axiomatic design

1. INTRODUCTION

According to one of the definitions of *electrochemical machining*, this processing method involves removing material from the workpiece due to an exchange of electrical charges and mass between the electrolyte, workpiece, and tool electrodes [1-5]. The zone involved in the process of the two important components of the process, the tool electrode and the workpiece, is immersed in an electrolyte that ensures the closure of the electrical circuit corresponding to the use of a current source with constant polarity. The last decades have confirmed the advantages of using pulses of determined characteristics at the level of the processing area. Like other nonconventional processing methods, electrochemical machining makes it possible to process workpieces made of hard materials but characterized by a certain electrical conductivity. Electrochemical machining is also used on surfaces that are difficult or really impossible to achieve by conventional machining processes. The removal of the material from the workpiece requires relatively high consumption of electricity.

Electrochemical machining processes can be classified primarily by taking into account how depassivation is performed. It is known that the product of chemical reactions between the electrolyte and the workpiece material can accumulate on the surface of the part by decreasing the intensity of the process of material removal from the or workpiece or even stopping this process. Natural depassivation, hydrodynamic depassivation, and abrasion depassivation, respectively, can be used to remove the passivating film.

From the point of view of machining schemes, several processes have similarities with the classical machining processes. Thus, processes of electrochemical drilling, electrochemical milling, electrochemical turning, etc., can be mentioned.

Electrochemical cutting processes have been developed to separate parts of the workpiece by electrochemical machining or for the generation of slits in workpieces made of electroconductive materials.

Research has been conducted on electrochemical cutting processes using a blade, disc, or wire tools. In the last two decades, special attention has been paid to wire electrical discharge cutting.

Thus, Fang et al. used a rotating helical electrode with a diameter of 0.3 mm to make slots in aluminium ring-type parts, using electrolytes based on green additives [6]. For a voltage of 9 V applied to the two electrodes, the machining speed was about 1.2 µm/s.

Meng et al. used a wire electrochemical micromachining process to make micro-cuts in Ni-based metallic glass parts [7]. They modified the voltage pulse waveform and electrolyte composition to improve the efficiency and stability of the process.

Zeng et al. investigated the wire electrochemical machining, looking at how the machining accuracy

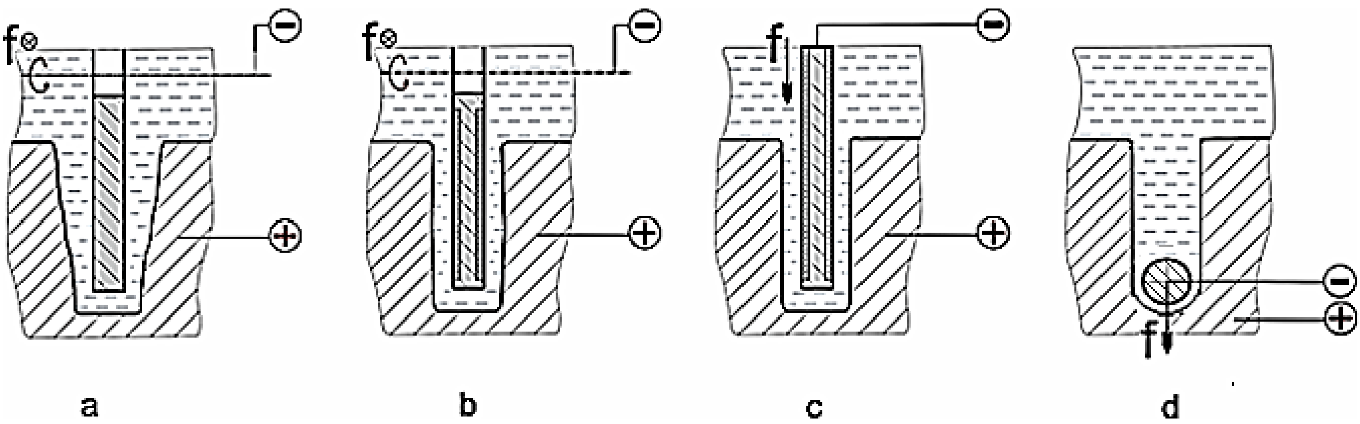

Figure 1. Penetration of the tool electrode in the workpiece at electrochemical cutting: a - cutting with unprotected disc electrode; b - cutting with disc electrode having the lateral surfaces coated with a layer of insulating material from the electrical point of view; c - cutting with a blade electrode having the lateral surfaces coated with a layer of insulating material from an electrical point of view; d - cutting with wire tool electrode

and process stability can be raised by changing the wire traveling velocity, feed rate, applied voltage, electrolyte concentration [8].

Concerns have also been identified for developing disc-type tool electrodes [1-5, 11].

Among the characteristics of technological interest specific to electrochemical processing in general and electrochemical cutting in particular, there is the non-existence of proper wear of the wire tool electrode. Given that electrochemical machining does not involve (at least in the case of processes with natural or hydrodynamic depassivation) a plastic deformation of the workpiece material, nor temperatures capable of producing thermal changes in the structure of the workpiece could not be observed as a result of using the electrochemical machining. Electrochemical machining is among the few machining processes with material removal from the workpiece, which does not produce mechanical or thermal changes in the surface layer obtained by machining.

In the research whose results are presented in this paper, the aim was to make equipment that allows cutting or making slits in workpieces made of materials that have internal stresses generated by heat treatments or other processing performed previously. In this way, it is expected that the mechanical balance between the different components of the part as a result of the application of an electrochemical cutting will be affected, and the deformations occurred after cutting to provide information on the types and values of residual internal stresses in the workpiece.

2. FUNCTIONAL REQUIREMENTS FOR ELECTROCHEMICAL CUTTING EQUIPMENT

The intention to build small equipment arose from a request to make a radial slit in a ring-type piece of steel difficult to cut by conventional machining processes, such as a hardened tool carbon steel or a high alloyed hardened steel.

In such a state, a workpiece can no longer be machined by conventional metallic cutting tools but only by machining using abrasive tools or by some nonconventional processes. As previously mentioned, residual stresses will be generated in the ring-type workpiece by hardening heat treatment. When making a radial slit to the central area of the workpiece, after material removal of the ring, under the action of residual internal stresses, it is expected that the width of the slit will change. The new slit width or sample diameter of the ring-type part could offer information relative to the type and size of internal stresses. As the process for making the slit in the ring-type sample mustn't generate additional residual stresses, other than those existing before making the slit, it was decided to use an electrochemical cutting process. Some axiomatic design principles have been used to define the functional requirements specific to electrochemical cutting equipment [9]. The first axiom in the axiomatic design highlights the need for the independence of functional requirements after these functional requirements have been developed on several levels.

Thus, the zero-order functional requirement (*FR*0) will have the form: to design equipment that allows achieving a radial slit set in a ring-type sample, to detect the presence and magnitude of residual stresses in the sample material.

Next, the functional requirements of the first order will be defined when the requests to which the equipment to be designed must respond in more detail.

Some of the first functional requirements will be, as such, the following:

*FR*1: ensure the existence of a tool electrode;

*FR*2: provide a possibility to locate and clamp the sample of electroconductive material;

*FR*3; ensure a possible electrode tool movement;

*FR*4: provide a possibility for the tool electrode to feed along a radial direction relative to the ring-shaped sample;

*FR*5: ensure that the tool electrode and the sample are included in an electrical circuit;

*FR*6: ensure the connection of the tool electrodes in the circuit of a current source with constant polarity;

*FR*7: ensure the direct current source;

*FR*8: ensure electrolyte access to the processing area;

*FR*9: ensure depassivation at the level of the machining area;

*FR*10: ensure that the equipment components used to locate and clamp the sample and the tank in which the machining process is to be carried out are not corroded.

The analysis of working conditions for the equipment whose constructive solution is to be identified will reveal other specific functional requirements. Still, we will limit ourselves to the ten functional requirements mentioned above, given the problems raised by their fulfilment.

3. ALTERNATIVES TO EQUIPMENT COMPONENTS

Starting from the existing information in the literature and from the practical experience gained, we will try to identify some possibilities to meet the functional requirements mentioned above. Obviously, for each of these functional requirements, distinct solutions to meet them can be identified. It was appreciated that highlighting the distinct solutions becomes possible by elaborating a so-called diagram of ideas.

Following the principles promoted by Professor Vitalie Belous, a diagram of ideas is a graphical representation in which the known embodiments of the product's various components to be obtained are highlighted [10].

Subassemblies or elements of the product may be effectively used as components of the product. Still, aspects such as the position of the components, their dimensions and shape, the colors of the components, etc., may also be taken into account. The use of those components could lead to innovative solutions for the targeted product. Specifically, as tool electrodes that can be used, we will find discs, blades, strips, or rectilinear wires fixed between two points or wires that move along their axis due to the winding on some rollers. The information in the literature focuses mainly on the use of continuous wire tool electrodes, as well as a wire that is driven in a movement along its axis, being supported and driven in motion using rollers, one of the rollers being the drive roller [6-8].

Suppose a continuous wire electrode machining scheme is adopted. In that case, a wire stretching solution will also have to be designed, given the need to ensure the straightness of the less rigid wire in the machining- area.

The locating and clamping of the sample can be done using clamps and screws if, in the interior of the tank in which it has processing, there is a table with T-shaped channels. Another variant of clamping could consider the use of a vise.

The tool electrode can be fixed or perform a rotational movement, a unidirectional rectilinear movement, or a rectilinear-alternative movement. Note that the movement of the tool electrode will contribute to a better depassivation of the working area through the possible removal of the electrolyte.

Suppose a fixed tool electrode variant could be considered for slits of very short length. In that case, it will be necessary to move the tool electrode forward to advance into the sample as a material is removed gradually. The feed movement could be performed manually, requiring special attention, so as not to produce electric discharges between the tool electrode and the workpiece, mechanically, at a constant speed, and with a speed that takes into account the processability of the ring material by electrochemical machining. The constant feed rate will have to be slower than the material removal rate from the workpiece material to avoid the generation of electrical discharges.

The inclusion of the tool electrode in the electric current circuit may require clamps and screws in a simple variant and respectively collector-brush ring subsystems, when the tool electrode makes a rotational movement or uses a continuous wire electrode, wound on some rollers.

The constant polarity current source could provide an approximative constant voltage current or a pulsating current. It can be seen that in recent decades, there has been a clear preference for the use of a pulsating source, given some of its advantages over constant voltage sources. Such advantages are related to the possibilities of monitoring and control of the machining parameters [2, 3, 5, 11].

The access of the electrolyte in the processing area is simple when the two electrodes involved in the process are immersed in the electrolyte. However, the possibilities of using solutions for recirculating the electrolyte in the tank or sending the electrolyte to the spray processing area could also be analyzed.

Depassivation is a problem with some of the solutions identified for other equipment components, as workpieces could be machined with natural depassivation, without the inclusion of specialized subassemblies to achieve depassivation. Depassivation also takes place when using a tool electrode whose active area achieves a circular or rectilinear movement.

An aqueous solution of sodium chloride, with different concentrations and which has the advantage of being cheap, could be used as the electrolyte. However, other aqueous solutions of some salts, acids, and bases can be identified.

It would be desirable for electrochemical erosion to occur only as long as the machining process develops and only in areas where workpiece material removal is intended. However, as some electrolytes can exert a corrosive effect even in the absence of electric current, it may be necessary to provide solutions to protect the surfaces of the parts immersed in or found in contact with the electrolyte. For this purpose, either metal parts may be protected with a layer of substance resistant to the corrosive action of the electrolyte solution, or plastic parts that are not normally corroded by the electrolyte shall be used. The arguments presented above in connection with the structure of specialized electrochemical machining equipment were summarized in the diagram of ideas in Figure 2.

A further step in using the information in the diagram of ideas involves combining alternatives for each of the components of the equipment, even in the

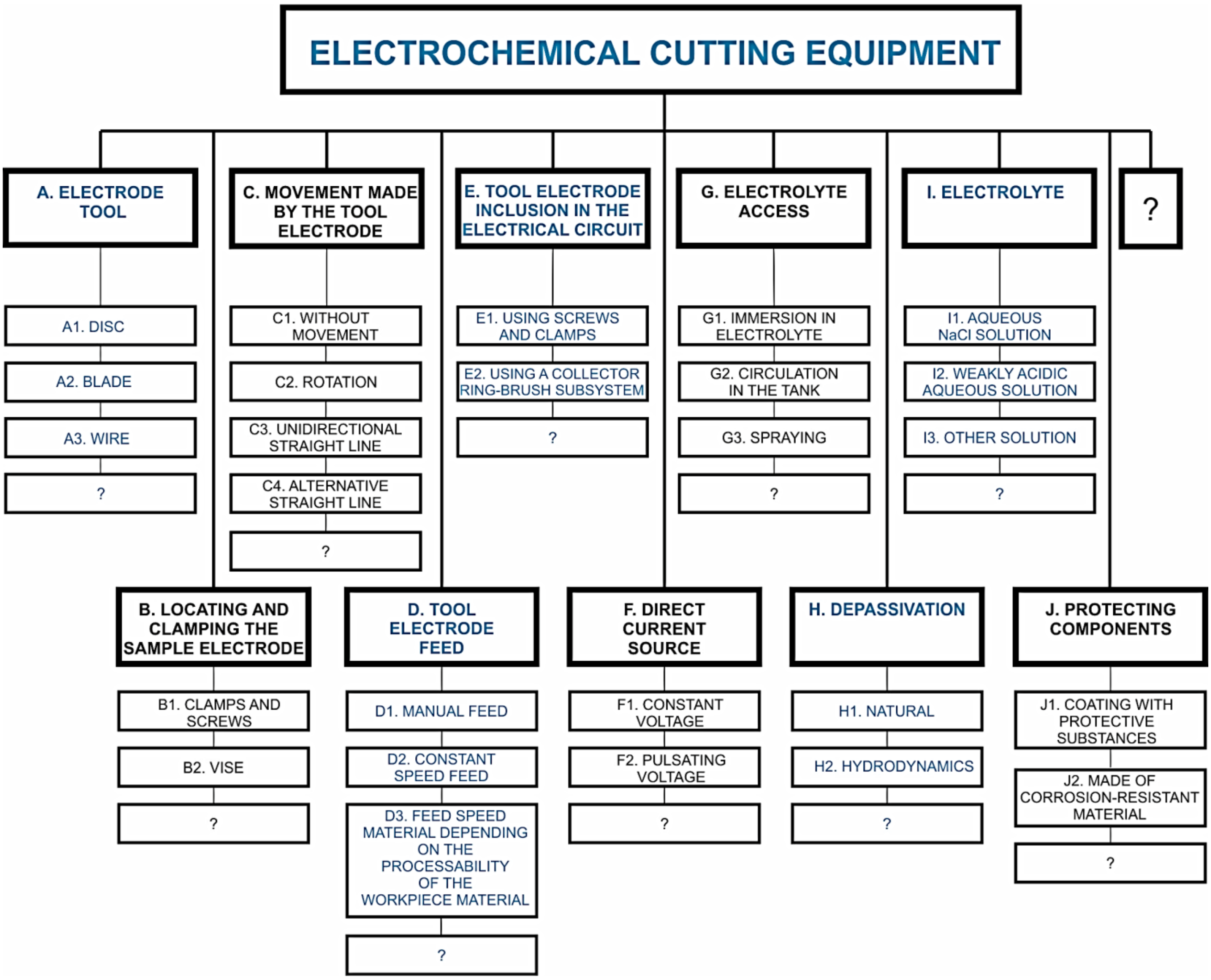

Figure 2. Diagram of ideas developed in the case of electrochemical cutting equipment

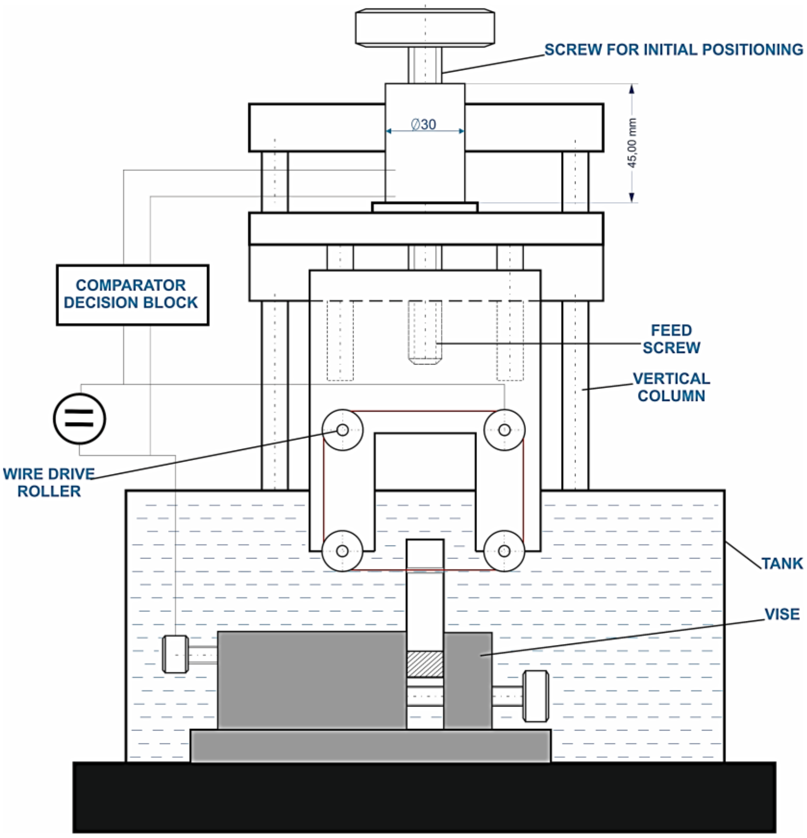

Figure 3. Proposed constructive solution for the electrochemical cutting device using the diagram of ideas

simplified form addressed in this paper. As relatively many components of equipment have been considered and several variants for each component respectively, the total number of possible combinations of alternatives will be large, according to a calculation relationship involving the multiplication of the numbers of alternatives for all components considered:

$$N_a=n_A\cdot n_B\cdot\ \dots n_I, \qquad (1)$$

where n_A, n_B, … n_I are the valid alternative numbers for components *A*, *B*, … *I*. In the specific case of electrochemical cutting equipment, this number of variants will be given by the relation:

$$N_a=3\cdot4\cdot2\cdot\cdot\ =10{,}368 \text{ alternatives} \qquad (2)$$

However, a detailed analysis of all those combinations of alternatives for the 10 components of the equipment requires a very long time. For this reason, it is recommended in the literature to use distinct methods to reduce the number of variants that will be examined in more detail later [10, 12]. In the latter case, it will be possible to use optimal selection methods of an alternative to solve the approached problem.

4. PRINCIPLE SCHEME OF THE EQUIPMENT.

In the case of electrochemical cutting equipment, the use of a global selection method was preferred, taking into account the authors' experience in the use of electrochemical machining processes. As selection criteria, the simplicity of the constructive solution and the possibilities of manufacturing the equipment were taken into account. This led to the solution shown in Figure 3. It can be seen that a solution has been preferred for the time being in which two rod-type guides have been used, on which, with the help of a screw, a slide to support the tool electrode can be initially positioned. Since the tool electrode is not affected by a wear process, but it should perform a working movement, to facilitate the development of a depassivation process, it was preferred to use a filiform electrode stretched between two supports and which will perform a rectilinear - alternative movement with the help of an electric motor and screw-nut mechanism.

When examining the diagram of ideas in figure 2, it can be seen that the selected variant corresponds to the combination *A*3*B*2*C*3*D*3*E*2*F*1*G*1*H*2*I*1J2. A more detailed analysis of the objectives to be met using the equipment and its manufacturing conditions could lead to changes in the components considered in the case of the simplified equipment represented in Figure 3.

5. CONCLUSIONS

Highlighting the internal stresses present in a metal part is possible in some situations by making a slit that facilitates the breaking of the initial balance of stresses in the part material and the occurrence of deformations whose measurement could provide information on the type and size of stresses existing in the material of the part. The achievement of the slit must be carried out by a process that does not itself generate new mechanical or thermal stresses in the material of the part. Following the fulfillment of this last requirement, the problem of making the slit by the electrochemical way was approached in the present paper. As it is necessary to design and manufacture electrochemical cutting equipment, the various alternatives for meeting the functional requirements of the equipment have been considered, as these functional requirements are defined in the axiomatic design. For each of the functional requirements, materialization alternatives have been identified. The search for alternatives was facilitated by using principles specific to the ideas diagram method as a method designed to stimulate technical creativity. From the possible combinations of the different variants of the components of the electrochemical cutting equipment, based on practical experience and information found in the literature, an alternative was selected. This alternative corresponds to the objectives pursued but is sufficiently simple and easy to manufacture. An alternative to electrochemical cutting equipment that considers the use of a wire electrode stretched between two supports and achieves an alternative rectilinear motion has been proposed. In the future, it is intended to identify other alternatives for electrochemical cutting equipment and to use a method that allows the optimal selection of the equipment variant. The materialization of the equipment will also allow the development of experimental research to verify the extent to which it is possible to achieve the proposed objectives.

6. REFERENCES

1. Ivan, M., *Systems and technologies of electrochemical machining. ECM* (in Romanian). Universitatea Transilvania, Brașov, Romania, {1995).
2. Marinescu, N.I. (coordinator), Chicu, C., Ghiculescu, DE., Herman, R., Ivan, M., Marinescu, N.I., Marinescu, R.D., Măniuț, P., Nanu, D., Obaciu, G., Pisarciuc, C., Popa, L., Sârbu, F.A., Țîțu, M., *Treaty of nonconventional technologies. Vol. IV. Electrochemical machining* (in Romanian). Publishing House Printech, Bucharest, Romania, (2006).
3. Turc, C., *Automation of the electrochemical machining* (in Romanian). Publishing House Eurobit, Timișoara, Romania, (2002).
4. Cuculeanu, G., Electrochemical machining. Publishing House Efficient, Bucharest, Romania, (1998).
5. Slătineanu, L., Nagîț, G., Dodun, O., Coteață, M., Munteanu, A., Beșliu-Băncescu, I., Gherman, A.-L., Hrițuc, A., Chinesta, F., Goncalves-Coelho, A., Teixeira, J.P., San Juan, M., Santo, L., Santos, F., *Electrophysical and chemical manufacturing processes*, Publishing House Tehnica Info Chișinău, Republic of Moldova, (2020).
6. Fang, X, Wang, X., Zhu, J., Zeng, Y., Qu, N., Wire electrochemical micromachining of aluminum rings for the fabrication of short-millimeter corrugated horns, *Micromachines*, Vol. 11, 122, (2020).
7. Meng, L., Zeng, Y., Zhu, D., Investigation on wire electrochemical micro machining of Ni-based metallic glass, *Electrochimica Acta*, Vol. 233, pp. 274–283, (2017).
8. Zeng, Y., Yu, Q., Fang, X., Xu, K., Hansong, L., Qu, N. Wire electrochemical machining with monodirectional traveling wire. *International Journal of Advanced Manufacturing Technology*, Vol. 78, pp. 1251–1257 (2015).
9. Suh, N.P., *Axiomatic design. Advances and applications*, Oxford University Press, New York, U.S.A, (2001).
10. Belous, V., *Inventics* (in Romanian). Publishing House Asachi, Iași, Romania, (1992).
11. Saxena, K.K., Qian, J., Reynaerts, D., A review on process capabilities of electrochemical micromachining and its hybrid variants, International *Journal of Machine Tools and Manufacture*, Vol. 127, pp. 28-56 (2018).
12. Slătineanu, L. *Fundamentals of scientific research* (in Romanian). Publishing House PIM, Iași, România, (2020).