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TEACHING STUDENTS THE BASICS OF DESIGNING EXPERIMENTAL RESEARCH EQUIPMENT

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ABSTRACT

This paper presents some considerations concerning the application of axiomatic design in research. In such a case, the researcher sometimes needs to quickly find equipment that is adequate to certain experimental conditions; thus, the researcher is both customer and designer. On the other hand, because the researcher must give creative solutions to some stages of the research, he could be interested in using methods capable of stimulating technical and scientific creativity. This paper discusses some of the results obtained in a Romanian technical university concerning the possibility to stimulate the students' creativity. A case study of the application of axiomatic design in order to develop a device for electrical discharge machining of curvilinear axis holes is also presented; this device was needed in a study in the field of non-conventional machining technologies.

Keywords: scientific research, experimental equipment, axiomatic design, creative design, curved hole, device for electrical discharge machining

1 INTRODUCTION

Generally, scientific research involves several stages. For the manufacturing engineering researchers, the main stages could be: formulation of the scientific research subject; documentation; elaboration of assumptions/hypotheses (theoretical research); experimental research in order to test these hypotheses; elaboration of conclusions and recommendations.

The experimental testing of assumptions may involve the presence of adequate equipment. Such equipment may already exist in the laboratory or it may be purchased from specialized suppliers.

In scientific research, there are often situations when the equipment needed in order to test certain assumptions is not found in the laboratory. Other times, the existing equipment is unable to provide adequate answers for the experimental stage. In such situations, new or improved equipment (experimental stand, experimental apparatus, tools for experimental research etc.) needs to be designed, manufactured and used.

Thus, a study may include a research sub-stage in which the researcher has to design and produce a certain piece of equipment or mechanical structure. In our case, this sub-stage could mean the use of axiomatic design.

In addition, improved or new equipment could represent an additional research contribution. Researchers know that their work and activities are better appreciated when they use new or improved equipment in experimental research. In fact, finding new or improved equipment for experimental or generally for practical activities is a permanent duty of the researcher and the engineer.

In accordance with the opinion expressed by the founder of axiomatic design, the concept of axiomatic design refers to a system design methodology using matrix methods to systematically analyze the transformation of customer needs into functional requirements, design parameters, and process variables [Suh, 2001]. Generally, axiomatic design is thus considered as a method for product research and design.

One must take into consideration the fact that a product is usually meant for the market. In the case of experimental research, the customer is the researcher and also the designer. A possible question is whether this double quality of the researcher could affect the results of the design activity.

Nowadays, a real contribution to the increase of the volume of scientific knowledge is made by the activities performed by PhD students, by postgraduate students and sometimes by undergraduate students in a certain scientific field.

Knowing this, universities are interested in finding and applying methods that develop the students' abilities for generating new scientific or technical knowledge. With this aim in view, the university curricula include subject-matters in which the students complete or renew their knowledge and skills in developing scientific research.

Thus, M. K. Thompson et al. [2009] appreciated that the engineering educational process has to make sure that the specialists it trains are able to solve a wide variety of engineering problems, but the educational process in the engineering field must also be able to educate future researchers [Thompson, 2009]. The authors analyzed the possibilities to apply axiomatic design to the educational process and concluded that one of the strengths of axiomatic design is that it steers the designer directly toward good designs without costly trial-and-error processes. Within the research activity there are some difficulties in completely avoiding the trial and error method, especially when there is not enough knowledge in that specific research field and when smaller steps in research are not possible. Such a situation can be found during the design and development of experimental research.

Aspects concerning the participation of the creative components of thought in the stages of application of the axiomatic design method were also analyzed by the specialists and researchers directly interested in solving practical problems in industrial activities.

For example, Janthong et al. [2010] combined axiomatic design and case-based reasoning in order to develop an innovative design methodology applicable for mechatronic products. They noticed that engineering design departments have to design new products using innovative principles. Such a situation is sometimes similar to that of the researcher who must develop a new piece of experimental equipment, while aiming to obtain valid experimental results.

Gonçalves-Coelho and Mourão [2007] took into consideration design as a tool for decision-making in the design activity for the manufacturing context. They considered that good decisions could be made on the basis of the best match between the system and design ranges.

Cavallucci and Lutz [2000] considered that an "Intuitive Design Method" could be based on the previous knowledge and background of a company, when one tries to increase the engineers' abilities to develop and to optimize a total design process.

Kulak, Cebi, and Kahraman [2010] noticed that axiomatic design was preferentially applied for the design of systems (considered as a process of defining architecture, components, modules, interfaces, and data in order to satisfy the defined requirements), for product design, software design and manufacturing systems design.

Urbanic and Maraghy [2009] proposed to couple some design procedures and axiomatic design methodologies in order to generate a platform for subsequent design modification. Of course, such a solution could be also applied in order to design new equipment for experimental research.

Nakao et al [2000] proposed specialized software which could be used as a creative design engine, consisting of a thinking operations engine, an engine for knowledge search, decision transfer CAD system and design knowledge database.

Sohlenius et al. [2002] appreciated that the innovation process has a certain logical structure, which needs to be followed in a decision process. They considered that in order to improve quality and productivity in industrial operations, a competence strategy must be combined with the business strategy. One of their conclusions was that there is a rich world of possibilities for the interested designers to model products and processes.

2 SPECIFIC ASPECTS OF USING AXIOMATIC DESIGN IN SCIENTIFIC RESEARCH

As mentioned above, in experimental research, the researcher (which may also be a PhD student or a postgraduate student) may be forced by the circumstances to design and manufacture experimental equipment. With this aim in view, the researcher could use:

- *classic/traditional design,* using design methods that allow him/her to reach his/her objectives fast. It is expected that the designed product does not incorporate innovative components.
- *creative design*, when one of the researcher's objectives is to obtain equipment that include at least a few innovative elements.

In creative design, the researcher could try to apply the axiomatic design method.

It is clear that, at least initially, being the only user of the equipment that needs to be designed, the researcher knows best the requirements that the equipment needs to meet. As a rule, the equipment is meant to solve a particular problem (to measure or to monitor the variation of a certain physical magnitude, to record a certain moment of the experiment evolution etc.). On the other hand, the researcher knows that in time, new ideas may require the development or modification of the equipment initially meant to solve only a narrow-scope problem. This means that the equipment to be designed must be easily modifiable, in order to ensure the flexibility needed in experimental research. Additional requirements may concern the manufacturability of such equipment; the researcher must take into consideration the feasibility of manufacturing the various components of the research equipment and of assembling them into a functional structure.

Of course, sometimes the researcher may ask professional designers and manufacturers to solve the problems of design and manufacturing for such equipment. In such a case, the researcher must have a very clear picture of the necessary equipment and the main functional requirements must be clearly specified to the professional designers and manufacturers, possibly even supplementing the request with detailed documentation.

Anther particular aspect derives from the fact that, as a rule, the product (the research equipment) is not designed for the market. Even when a real probability that the product will enter the market in the future is remote or inexistent, some issues concerning market-specific requirements (manufacturing cost, providers of specialized parts etc.) could be taken into consideration. These issues, however, are not of real interest for the researcher and for the most part they are neglected during the design process.

3 SOLVING THE PROBLEM OF IDENTIFYING A SOLUTION THAT INCLUDES INNOVATIVE ELEMENTS

An additional requirement for the researcher is that the design should include innovative elements. In order to meet such a requirement, methods for the stimulation of technical and scientific creativity may be applied.

Over the past few decades researchers have endeavoured to propose and apply various methods to stimulate creativity in various fields of human activity.

The concept of *creativity* seems to have been used for the first time by American psychologist Gordon Allport. In a paper published in 1937, he defined creativity as an integrative way by which the human being manages not only to understand, to reproduce and to solve the numerous problems that life poses, but also to show a number of qualities that would result in new and original solutions [Căpâlneanu, 1978].

Creativity is influenced by *biological factors* (genetic potential, memorisation capacity, age, sex, state of health etc.), *psychological factors* (imagination potential, aptitudes, temperament, volitional qualities, motivation, curiosity etc.), *cognitive – intellectual factors* (specialized intellectual skills, specialized intellectual training etc.), *gnoseological* factors (level of education, lack of knowledge concerning the necessary stages of the innovation process, concerning the intuitive and logical techniques and methods for stimulating creativity, a low quantum of specialty knowledge, lack of lateral knowledge etc.), *socio-economical factors* (school, family, living standards, socio-professional environment, style of leadership in the workplace, communication systems, work conditions, opportunities to obtain technical information, the way creative activities are organised, assessed, supported, rewarded and encouraged, the existence of innovative groups, social climate etc.), *hazard/chance* etc. [Slătineanu and Duşa, 2002]

Of course, there are various techniques and methods able to stimulate technical and scientific creativity. Among them:

- *Intuitive techniques*; there are techniques that rely on changing the position from which the problem to be solved is examined, techniques that rely on highlighting the correlations between objective and words or images selected logically or at random (association technique, catalogue use, attribute inventories, using randomly selected words, plays on words etc.), and techniques based on changing a known solution in terms of quantity or quality,
- *Intuitive methods*; in this group may be included: the lateral thinking method, the method of association chains, group discussion, brainstorming, synectics, the Philips 66 method, the Delphi method, the Frisco method, the Panel discussion method, the 6-3-5 method etc.;
- *Logical techniques and methods* that may be *applied in order to identify new or improved solutions* (the method of morphological matrixes, the diagram of ideas etc.).

University education considers the stimulation of the students' creativity and abilities in producing new or improved scientific and technical knowledge as one of its main objectives.

At the "Gheorghe Asachi" Technical University of Iaşi (Romania), which trains the future specialists in the field of industrial engineering, the students could become acquainted with the method of axiomatic design by means of constructive design subject-matters (machine elements, cutting tools design, technological devices design, machine-tools design etc.).

Before approaching the actual methods of designing various mechanical structures, the students are trained in using and stimulating their creativity during course called *Fundamentals of the technical creativity*. This course is taught as two hours of lectures and one hour of applicative activities per week, during a 14-week term; the course is intended to the undergraduate students and it is to be held during the first semester of the third academic year.

The curriculum deals with topics such as the importance of the information concerning scientific and technical creativity, the stages of creative activity, the factors that may affect technical and scientific creativity, intuitive and logical methods for stimulating technical and scientific creativity and the capacity to identify new or improved solutions, protection of the intellectual property, and writing patent applications.

From the very beginning, the students are encouraged to find their own topics to be approached for improvement during the applicative activities of the *Fundamentals of the technical creativity* course. Their efforts are channelled towards finding topics in everyday life and activity that are susceptible to improvement: activities that are difficult to perform, boring /repetitive and/or tiring activities etc. On the other hand, the teaching assistants also prepare topics that may be interesting to the students.

At the end of these applicative activities, the students learn how they can write the documentation for registering a patent application. Thus, they can really develop and patent their own ideas for improving various objects and processes. At the time when the fees for the registration and examination of patent applications were affordable, about 75 % of the students used to send their proposals to the Romanian State Office for Inventions and Trademarks, and some of them have actually obtaining patents for their ideas. As a result of these activities aimed at stimulating student creativity, there were times when 10% of registered Romanian inventions originated at the Technical University of Iaşi. Nowadays, the fees for registering and examining patent applications are relatively high and this has led to a drastic decrease of the number of patent applications submitted by students.

A critical aspect specific to applicative activities concerns the lesser accent placed on the economic aspect of the solutions suggested by the students, on the possibility that these solutions be not only new or improved, but efficient as well. Initially we thought that too many constraints would diminish the students' creativity and their desire to be involved in finding new or improved solutions. Nowadays, the economic situation forces us to increase the weight of such aspects (including economic ones).

As a rule, the resolutions of the Romanian patent authority are sent to the applicants after 6 to 30 months (most often after 24 - 30 months). For student D. Răzmireş (in 1994), the resolution (a patent for a device for electrical discharge machining) arrived after only 6 months. The student was so encouraged by this result, that before graduation he developed several dozen inventions. This was, of course, an exceptional situation.

4 CASE STUDY – DEVICE FOR THE ELECTRICAL DISCHARGE MACHINING OF CURVED HOLES

4.1 PROBLEM DEFINITION

Electrical discharge machining is a machining method which uses electrical discharges initiated between a tool electrode and a workpiece in order to remove material from the workpiece (fig. 1). An electronic generator provides the electrical pulses necessary for the electrical discharges. There are electrical discharge machining methods where so-called massive electrode tools are used in order to obtain various profiled surfaces, and methods that use wire electrodes in order to separate parts from the workpiece.

Electrical discharge machining of curved holes may be included in the first group mentioned above. Generally, there are significant difficulties in obtaining curvilinear holes by using so-called classical machining methods (by classical cutting or by plastic deformation).

The current ram electrical discharge machine-tools are usually equipped with numerical control systems and a curvilinear path of the tool electrode can be obtained relatively easily on such machine-tools if they have a numerically controlled rotation axis. Factories are usually equipped with old electrical discharge machine-tools or with CNC electrical discharge machines that cannot be used to obtain curved holes. For this reason, the issue of finding a device for electrical discharge machining of curved holes was approached by the non-conventional technologies laboratory at the "Gheorghe Asachi" Technical University. In order to meet research requirements, this device had to be installed on a ram electrical discharge machine and adapted in order to allow the study of influences exerted by work conditions (pulse duration, average current, diameter of the tool electrode etc.) on the parameters of technological interest (material removal rate, tool electrode wear, roughness of machined surface etc.). On the other hand, the electrical discharge machining process (fig. 1) involves the periodic partial withdrawal of the tool electrode from the bottom of the hole that is being drilled, in order to allow the refreshment of work liquid in the space between the electrodes (work gap). Indeed, such to-and-fro movements of the tool electrode generate an effect of suction and discharge and thus, the refreshment of at least part of the dielectric liquid found in the gap is possible.

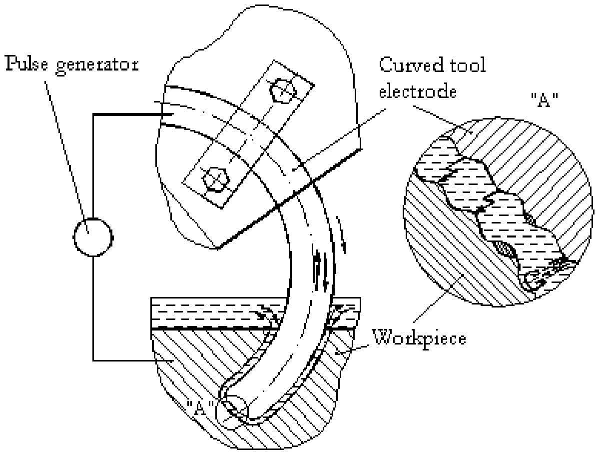

Figure 1. Work conditions in the case of electrical discharge machining of curved holes.

PhD students and postgraduate students were involved in solving the abovementioned problem (designing a device for electrical discharge machining of curved holes). They tried to use various techniques and methods for creativity stimulation.

On the other hand, it is known that in management there is a principle saying that when an important problem seems to have only one solution, there is a high probability that this solution is not the best one [Ghinea, 1973]. This means that the designer must find and analyse other solutions as well for the device being designed. At this stage, the designer may use some creative methods in order to identify other solutions that would meet the original requirements.

4.2 APPLICATION OF THE IDEAS DIAGRAM METHOD

Whenever they have to identify options for mechanical equipment, the students (including the PhD students) of the Technical University of Iași usually use *the diagram of ideas* [Slătineanu et al., 2009]. From certain points of view, the diagram of ideas could be considered as somewhat similar to functional requirements (FR) decomposition [Urbanic and Maraghy, 2009]. Essentially, this diagram helps them identify the possible components of the equipment and the options they offer, the possible combinations of components, and the extent to which the various solutions found adequately meet the previously established criteria and constraints. Afterwards, all of the resulting combinations or only some of them are analyzed more in detail, in order to find out whether a certain combination/several combinations represent an element of progress.

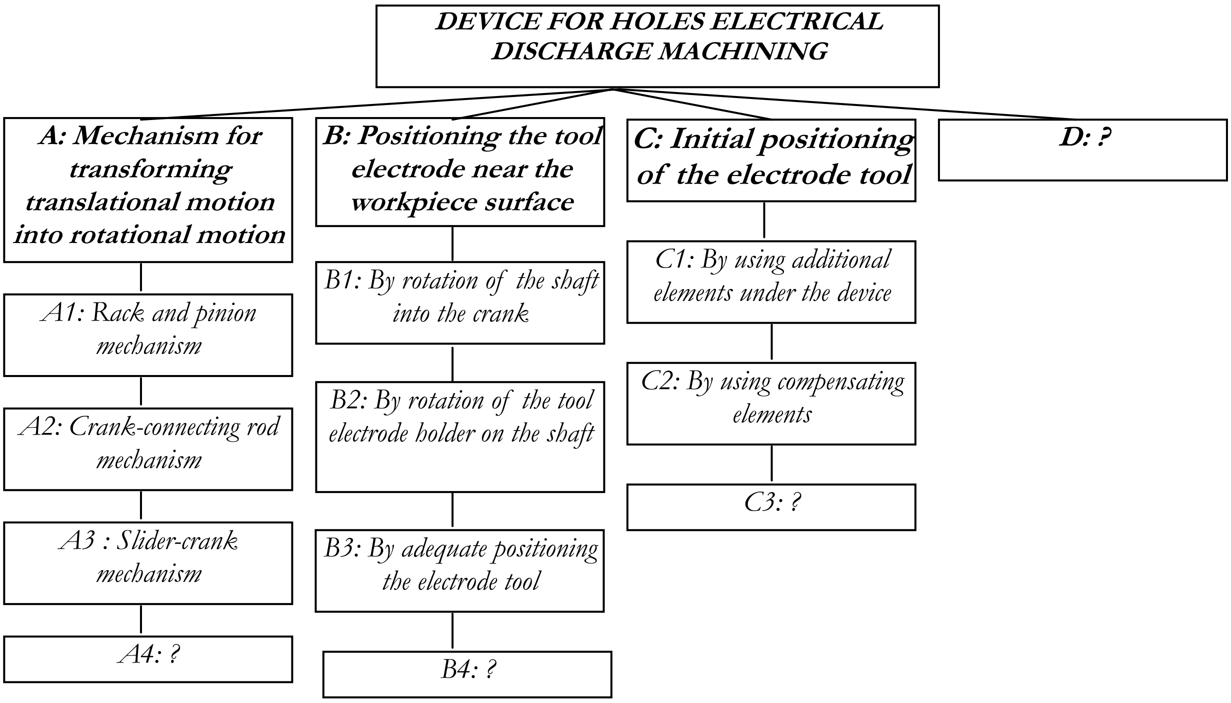

Figure 2. Simplified ideas diagram used to obtain more options corresponding to a device for curved hole electrical discharge machining.

In the case of the device for drilling curved holes by electrical discharge machining, a simplified diagram is presented in figure 2. Several subassemblies of the device were identified, together with the various ways of materializing each subassembly. For example, in order to change the rectilinear motion of the work head of the ram electrical discharge machine into a rotation motion of the tool electrode holder, the designer is faced with several options: a crank-rod mechanism, a slider-crank mechanism, a rack and pinion etc.

4.3 USING THE VALUE ANALYSIS METHOD

When there are too many constraints, and the selection

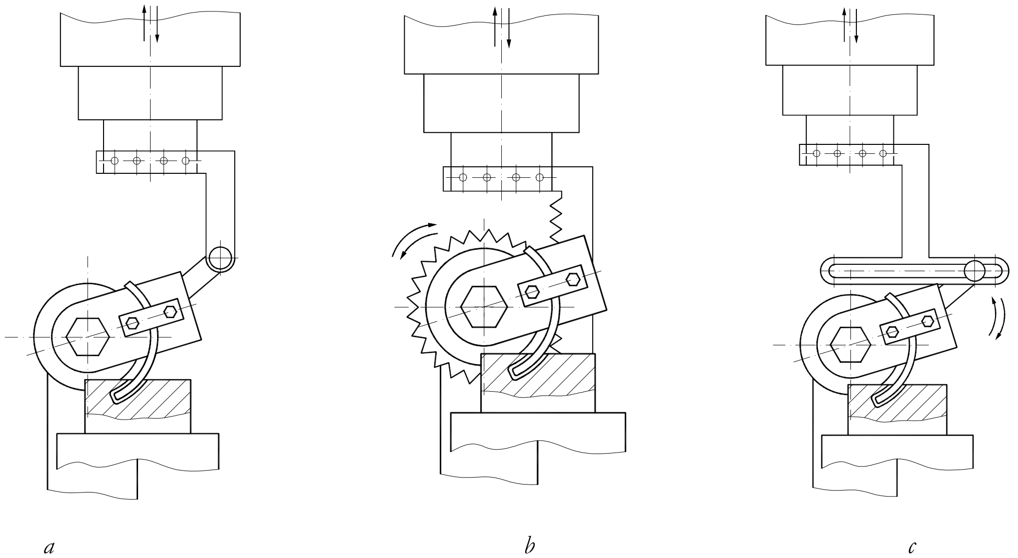

Figure 3. Three versions of the device for electrical discharge machining of curved holes: a – device with crank – connecting rod; b – device with rack and pinion; c – device with slider-crank mechanism.

Table 1. Determining the coefficient of importance for each evaluation criterion.

Criterion j	Decision number						Sum N_{dj}	Coefficient of importance K_j
	1	2	3	4	5	6		
A	1	0	0				1.00	0.166
B	0			0.5	0		0.50	0.083
C		1		0.5		0	1.50	0.166
D			1		1	1	3.00	0.333

of the main constraints is difficult, some value analysis procedures could be taken into consideration. It is known that in such a case, by comparing the identified constraints two by two, and by giving them adequate weights, coefficients of importance may be calculated for all the constraints; a more adequate order of the constraints can be thus established and the constraints with low importance coefficient values may be left out.

For example, a simplified model of a value analysis application could take into consideration three versions of a device for electrical discharge machining of curved holes (fig. 3). These versions may be identified by applying the diagram of ideas. The three versions are the following: *a* – device with crank-connecting rod; *b* – device with rack and pinion; and *c* – device with slider-crank. The main stages of applying the method of value analysis are presented below.

1) Listing the evaluation criteria. Let us assume that in the case of the device for electrical discharge machining of curved holes the following four criteria are used: *A* – constructive simplicity; *B* – manufacturability of the device parts; *C* – Low cost; and *D* – Fast reaction to withdrawal of the electrical discharge machine head. Of course, in the actual circumstances of industrial practice, many such device versions and evaluation criteria can be considered.

2) Weighting and re-ordering the evaluation criteria. By successively comparing the criteria two by two, the pairs can be assigned decision values as follows: 1-0 (the first version is superior), 0-1 (the second version is superior), 0.5-0.5 (the two versions are considered equally valuable). The valid decisions in the example under consideration were included in table 1. The total number of decisions is given by the relation:

$$D_c = \frac{N_v\left(N_v - 1)\right)}{2} \tag{1}$$

where N_v is the number of considered criteria. For our example, the number of decisions is D_C =4*3/2=6.

In table 1, the penultimate column contains the sum N_{dj} of the decisions, for each of the evaluation criteria *j* (the evaluation criteria being *A*, *B*, *C* and *D)*. In the last column, the coefficients of importance K_j for each version *i* of device were written:

$$K_j = \frac{N_{dj}}{D_c} \tag{2}$$

3) Comparing the considered versions and determining the value number N_{vi} corresponding to each version i. The comparison takes into consideration each applied evaluation criterion *j*; the results were included in table 2. The same method of evaluation (by using decisions type 1-0, 0-1 or 0.5-0.5) was applied in order to compare the versions of a device for electrical discharge machining of curved holes. The last of the columns assigned to a certain criterion *j* includes the coefficient of importance K_{ij} corresponding to each version *i* of the device, established by means of criterion *j*.

The value number N_{vi} for each considered version *i* is given by:

$$N_{vi} = \sum_{j=1}^{N} K_{ij} K_j \tag{3}$$

where K_{ij} are the coefficients of importance for each of the variants *a*, *b* and *c*, determined successively for each of the criteria *j* (the criteria *A*, *B*, *C*, and *D*), and K_j are the coefficients of importance corresponding to each criterion j.

Table 2. Elements for determining the value numbers corresponding to the analyzed versions in the case of the device for electrical discharge machining of the curved holes.

Version	Criterion *A*					Criterion *B*				
	Decision			Sum N_{di}	Coeff. of importance, K_{ij}	Decision			Sum N_{di}	Coeff. of importance, K_{ij}
	1	2	3			1	2	3		
a	1	1		2	0.666	1	1		2	0.666
b	0		0	0	0	0		0	0	0
c		0	1	1	0.333		0	1	1	0.333

Version	Criterion *C*					Criterion *D*				
	Decision			Sum N_{di}	Coeff. of importance, K_{ij}	Decision			Sum N_{di}	Coeff. of importance, K_{ij}
	1	2	3			1	2	3		
a	1	0.5		1.5	0.5	1	1		2	0.666
b	0		0	0	0	0		0.5	0.5	0.166
c		0.5	1	1.5	0.5		0	0.5	0.5	0.166

In the case of each version i corresponding to the device for electrical discharge machining of curved holes, the value number N_{vi} is:

$$N_{va} = 0.666 \cdot 0.166 + 0.666 \cdot 0.083 + \\ + 0.5 \cdot 0.166 + 0.666 \cdot 0.333 = 0.470612 \quad (4)$$

$$N_{vb} = 0 \cdot 0.166 + 0 \cdot 0.083 + \\ + 0 \cdot 0.166 + 0.166 \cdot 0.333 = 0.055278 \quad (5)$$

$$N_{vc} = 0.333 \cdot 0.166 + 0.333 \cdot 0.083 + \\ + 0.5 \cdot 0.166 + 0.166 \cdot 0.333 = 0.221195 \quad (6)$$

Depending on the value numbers N_{vi}, the most convenient solution i is the solution of the device based on the using of a crank – connecting rod mechanism (solution *a*), whose value number N_{vi} is the highest (0.470612 > 0.221195 > 0.055278).

Once the general picture about the selected device is established (which uses a crank – connecting rod mechanism), the issue of the axiomatic design of the device could be considered.

5 CASE STUDY – ELEMENTS OF APPLYING THE AXIOMATIC DESIGN METHOD

In order to apply the axiomatic design method in the case of a device for the electrical discharge machining of curved holes*, the customer needs* could be the following:

1) The device needs to be adaptable on a certain ram electrical discharge machine, having a work space characterized by known dimensions, by a certain solution for clamping the tool electrode on the work head of the electrical discharge machine, by certain ways to clamp the workpieces in the work tank etc.;

2) The device needs to be able to allow the change in the magnitude of certain mechanical work parameters (the work speed v_E of the curvilinear tool electrode in comparison with the work speed of the tool electrode in rectilinear motion, possibilities to modify the arch radius, etc.).

The identification and formulation of the functional requirements to be used in the axiomatic design is not always a simple problem. The researcher who is interested in designing and producing equipment for experimental research is tempted, but also obliged to take into consideration a high number of constraints or design requirements.

For example, in the case of the abovementioned device for obtaining curved holes by means of electrical discharge machining, a complex evaluation could result in a high number of requirements to be met. Such requirements may refer to the dimensions of the space where the device can be placed, to a cheaper constructive solution, to a device for which the necessary materials are easily available, simple maintenance, easy identification of defects and easy repair etc. It is clear that not all of these requirements will become functional requirements applicable when using axiomatic design.

In order to apply the axiomatic design method in developing a solution for the device for electrical discharge machining of curved holes on a ram electrical discharge machine, using a crank-connecting rod mechanism, the functional requirements *FRs* could be the following:

FR0: Clamping the curved tool electrode and ensuring a reciprocating circular motion (specific to the operating conditions of the electrical discharge machining process) of the tool electrode

FR1: Ensuring the clamping of the tool electrode on the tool electrode holder

FR2: Changing the rectilinear motion of the electrical discharge machine head into a circular motion

FR3: Ensuring the position of the tool electrode near the workpiece surface, at the start of machining

As second-level functional requirements, one can take into consideration

FR1.1: Positioning the curved tool electrode in the tool electrode holder

FR1.2: Securing the curved tool electrode in the tool electrode holder

FR1.3: Accepting tool electrodes with various cross section diameters

FR2.1: Changing the reciprocating rectilinear motion of the electrical discharge machine head into a reciprocating circular motion of the tool electrode

FR2.2: Ensuring a minimum delay for the change in motion direction

FR2.3: Easy change of the speed of the tool electrode circular motion, for the same speed of the rectilinear motion of the electrical discharge machine head

FR3.1: Continuous movement of the tool electrode towards the workpiece surface

FR3.2: Stopping the motion at a certain distance between the tool electrode and the workpiece surface

The design parameters *DPs* for the first-level functional requirements could be:

DP1: Tool electrode holder having arch-shaped grooves

DP2: Mechanism for transforming rectilinear motion into circular motion

DP3: Extensible subassembly

Apart from the abovementioned second-level functional requirements, the following design parameters DPs could be taken into consideration:

DP1.1: Arch-shaped grooves on the tool electrode holder

DP1.2: Securing clip and two screws

DP1.3: Angular grooves on the tool electrode holder

DP2.1: Crank and connecting rod mechanism

DP2.2: Minimum play in the crank and connecting rod mechanism

DP2.3: Possibility to change the radius of the crank

DP3.1: Free movement of the tool electrode holder, so that the curved tool electrode may move towards the workpiece surface

DP3.2. Blocking subsystem for stopping the curved tool electrode at a certain distance from the workpiece surface

By formulating the functional requirements for the first level, one can notice that the independence axiom is respected, because each requirement can be met independently of the others.

The matrix expression resulted in a diagonal matrix:

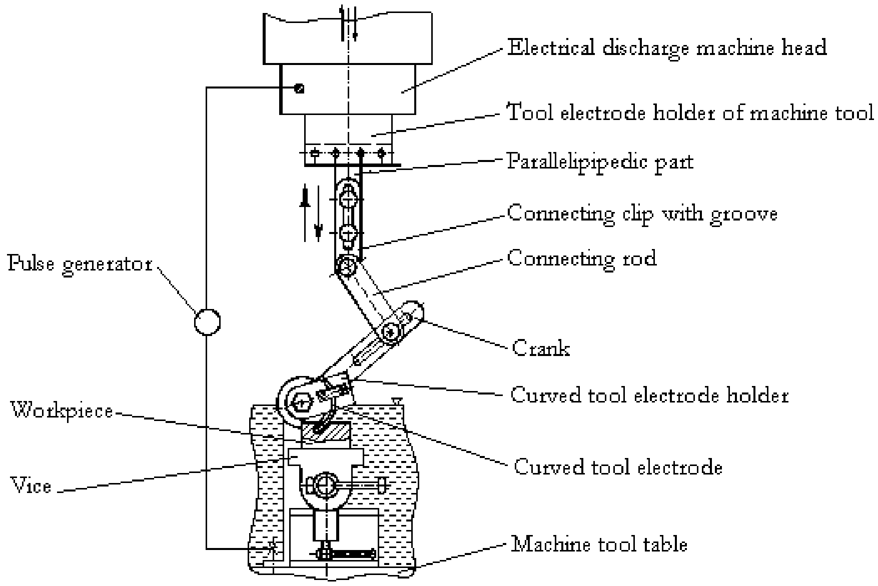

Figure 4. Device for curved hole electrical discharge machining.

$$\begin{Bmatrix} FR_1 \\ FR_2 \\ FR_3 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP_1 \\ DP_2 \\ DP_3 \end{Bmatrix} \qquad (7)$$

For most of the decomposition levels, there are uncoupled designs. An exception occurs in the case of the matrix attached to the first functional requirement *FR1* and the first design parameter *DP1*, when a decoupled design could be considered, due to the fact that the angular grooves must ensure the possibility to clamp curved tool electrodes having various diameters of the cross sections.

$$\begin{Bmatrix} FR1.1 \\ FR1.2 \\ FR1.3 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ X & 0 & X \end{bmatrix} \begin{Bmatrix} DP1.1 \\ DP1.2 \\ DP1.3 \end{Bmatrix} \qquad (8)$$

When establishing the design parameters DPs, the designer could already formulate some ideas concerning the structure of the device.

Essentially (fig. 4 and fig. 5), a parallelipipedic part is clamped in the tool electrode holder of the electrical discharge machine; along the free side of the parallelipipedic part, a connecting clip can be moved and secured in a certain position, by means of two screws.

When the electrical discharge machine work head moves vertically, the motion is transmitted by a connecting rod to a crank which can be rotated round of the axis of the shaft. This shaft is supported by a bearing placed on the machine tool table. At the other end of the shaft, there is a plate acting as the curved tool electrode holder. It has an arch-shaped groove (with an angular shaped cross section), where the tool electrode (having a circular cross section) can be clamped by means of a securing clip and two screws. Thus, the rectilinear motion of the machine tool head is changed into a circular motion of the tool electrode, around the shaft axis. The correct positioning of the tool electrode ensures the conditions for the gradual development of a circular hole in the workpiece, as a consequence of the electrical discharge machining process.

A vice placed on the machine tool table is used for positioning and clamping the workpiece. A groove existing in the crank can be used to change the position of the crank pin and, thus it is possible to change the shaft rotation speed, even though the rectilinear motion speed of the machine tool

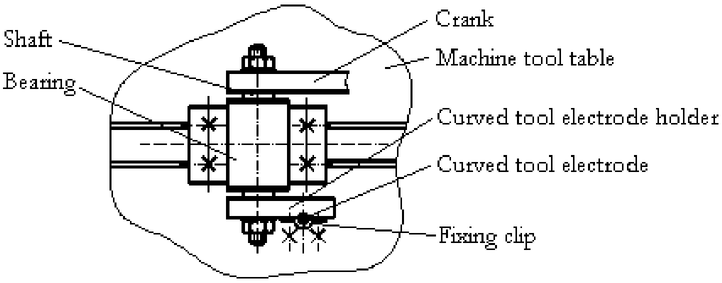

Figure 5. Rotation of the curved tool electrode holder round of the shaft axis by means of the crank.

head remains constant.

In this paper, the axioms were used in order to clarify the functional requirements that need to be met by the device for electrical discharge machining of curved holes, and to find adequate answers to these requirements. Of course, the axioms can be also used to prioritize the identified versions of the device. Such a problem (prioritizing the alternatives) was tackled and developed by Shin et al., [2002] in order to design a beam adjuster for a laser marker.

6 CONCLUSIONS

Sometimes, in order to carry out experimental research, the researcher has to design and produce equipment that would assist in creating the necessary experimental conditions. Research activities are better appreciated if this equipment includes innovative elements. To better solve design problems, the researcher can apply the method of axiomatic design; in such a situation, the researcher is both customer and designer. Some stages of the axiomatic design need to make effective use the researcher's creativity. At the Technical University of Iaşi – Romania, a course called *Fundamentals of technical creativity* was introduced in the university curriculum in order to stimulate the students' creativity. During the lectures and applicative activities of this course, students learn about various methods of creativity stimulation and about the factors that may affect creativity. Some aspects concerning the use of axiomatic design and methods of stimulating technical creativity were considered in the case of a device for curved hole electrical discharge machining. In the future, we intend to improve the device for curved hole electrical discharge machining by taking into consideration other constraints, such as the possibility to easily clamp tool electrodes with curvature radii having any value within a certain dimensional interval; such a problem could be tackled and analyzed also by applying the axiomatic design method.

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