Proceedings of ICAD2013
The Seventh International Conference on Axiomatic Design
Worcester – June 27-28, 2013
ICAD-2013-13

USING CREATIVE RESOURCES IN APPLYING AXIOMATIC DESIGN

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ABSTRACT

In order to increase the participation of creative components of thinking in certain stages of applying Axiomatic Design, one considered the use of the ideas diagram method. This could be made when the design parameters are established or by establishing functional requirements and design parameters so that the principles valid in the case of the ideas diagram method may be applied. A case study concerning a technological solution of detaching cylindrical parts from a metallic workpiece by electrical discharge machining was used in order to illustrate the possibilities of increasing the creative character of certain stages of applying Axiomatic Design.

Keywords: Axiomatic Design, functional requirements, design parameters, ideas diagram method, electrical discharge machining.

1 INTRODUCTION

A largely accepted definition of Axiomatic Design shows that this is a design methodology that uses matrix methods in order to analyze the transformation of customer needs into functional requirements, design parameters, and process variables [Gonçalves-Coelho, 2009; Suh, 1990].

For the innovative designer, a problem could refer to those stages of Axiomatic Design where technical/engineering creativity could have a significant role and it could be efficiently used. Over time, researchers have tried to include substages able to ensure a creative character to the activities involved by applying Axiomatic Design.

Thus, Crowell and Gregson [2008] proposed the use of a so-called Creativity Matrix, in order to integrate a tool for creativity into design process. They highlighted the significance of analysis and synthesis, as essential components of the cognitive psychology within Axiomatic Design.

M.K. Thompson [2009] studied the problem of the intersection between design and analysis; she appreciated that analysis is an element of design thinking and that design and analysis are interrelated.

Mann [1999; 2002] analyzed some of the compatibilities and contradictions between the theory of inventive problem solving (TRIZ) and Axiomatic Design. He concluded that the analytical methods of Axiomatic Design could complement the synthesizing capabilities of TRIZ in at least certain significant areas. An aspect of high importance was considered the recognizing and utilizing of the inter-dependences existing between both hierarchical layers and different hierarchical regimes specific to Axiomatic Design.

Brown [2005] showed that Axiomatic Design could develop engineering design from an iterative, abstract and intuitive process, relied essentially on creativity, into a science based on applying principles.

Thompson [2011] defined design as a "human activity which combines resources (knowledge, skills, experiences, creativity, tool, materials, etc.) to meet a need, accomplish a goal, or create an artifact".

During the design activities developed along a certain period, the designer succeeds to find and apply personal creative modes, in order to creatively solve design problems. Kim *et al.* [2011] showed that in order to find a solid and original solution, an adequate distribution and interaction between the problem and solution spaces could be required; one could find here a similarity with the zigzagging activity specific to Axiomatic Design. Kim *et al.* considered also that the designer's personal creativity modes are able to exert influence on the design activities in terms of design information and process.

In Axiomatic Design, if one analyses the content of the zigzagging activity, one may notice that sometimes, for each functional requirement, one tries to find a single design parameter and, usually, if this parameter is found, one considers that the problem specific to this stage is solved. This could generate an enhance of the creativity by eliminating bad ideas early [Suh, 2001], but sometimes some design parameters could offer maximum results only in the presence of a certain type /size of other design parameters, or if only a design parameter is available, the above mentioned analysis could not be developed.

During the presentation of his work [Park, 2011] concerning the ways of teaching Axiomatic Design to students and practitioners, Park highlighted the necessity of increasing possibilities of Axiomatic Design to find and apply innovative solutions for the design problems.

Some techniques and methods were applied within didactic applicative activities aiming the development of the students' creative capacity [Seghedin, 2010; Slătineanu *et al.*, 2011]. One can appreciate that in our situation (training students in field of mechanical and industrial engineering), among the simpler methods, the one based on the use of the ideas diagram method led generally to positive results: some authors considerations about such an aspect are presented in this paper.

2 INCLUSION OF A CREATIVE METHOD IN APPLYING AXIOMATIC DESIGN

Most methods aimed at the stimulation of technical creativity firstly are based on finding many solutions able to solve the problem and only subsequently the problem of identifying the most convenient of these solutions is approached. This means that during the stage of the zigzagging specific to applying Axiomatic Design, it is important firstly to find many design parameters (Figure 1). This supposes the use of divergent thinking. Afterwards, when it is necessary to determine the most convenient solution, the role of the convergent thinking becomes significant.

The main actor in the design activity is the designer; in order to solve a design problem, he could be usually obliged to select one of the following design methods:

- A routine design method, applied when operative solving of a certain situation/problem is necessary and when he does not search new and creative solutions. In accordance with [Dym, 1994], in case of routine design, just from beginning the designer knows what he needs in order to elaborate a design;

- A creative design method, which must lead to new solutions. This design method needs a longer time and it could not be strictly normalized. Applying this method supposes stages of documentation, operative activities, incubation stage, illumination sequence or stage, validation stage etc.

During the last decades, various methods were identified and applied, in order to stimulate human creativity in finding innovative solutions. Essentially, such methods intend to avoid the routine and to place design out of common ways of thinking.

In time, especially due to the daily routine, the designer structures a proper design algorithm, a proper way of searching the solutions for the design problems, on the basis of his previous academic training, of knowledge/experience accumulated and of success obtained by applying various design methods. Generally, once accustomed with a certain design method, the designer gives up difficulty to his proper algorithm used in order to search and to find new/improved solutions, especially when an eventually new design method supposes many stages and long duration of familiarizing with respective stages.

If we take into consideration Axiomatic Design, we could formulate a question about the position of a creative method within the stages specific to the use of Axiomatic Design where the designer's creative capacities could be efficiently applied.

In our opinion, such a more intense use of designer creative capacities could be materialized during the establishing of design parameters (Figure 1), when zigzagging between functional requirements and design parameters could facilitate the shaping of new or improved solutions for the approached problem. In such a case, elements based on the initial use of the ideas diagram method could be applied in one of the following ways:

a) A first way could be the shaping of an initial solution for the problem to be solved by direct elaboration of an ideas diagram, immediately after the functional requirements were established [Slătineanu *et al.*, 2011]. Essentially, within application of this method of creativity stimulation, during the stage of the problem analysis, a general solution is thought, by considering the components of the solution and trying to find various versions for each of the components; subsequently, in the synthesis stage, the combinations of various components are considered, in order to establish which combination is the most convenient of them. One appreciates that this method (the method of the ideas diagram) applied in order to stimulate the technical creativity could be used inclusively in the first stages of the Axiomatic Design method.

Thus, an ideas diagram could be designed by taking into consideration a known solution and which could be

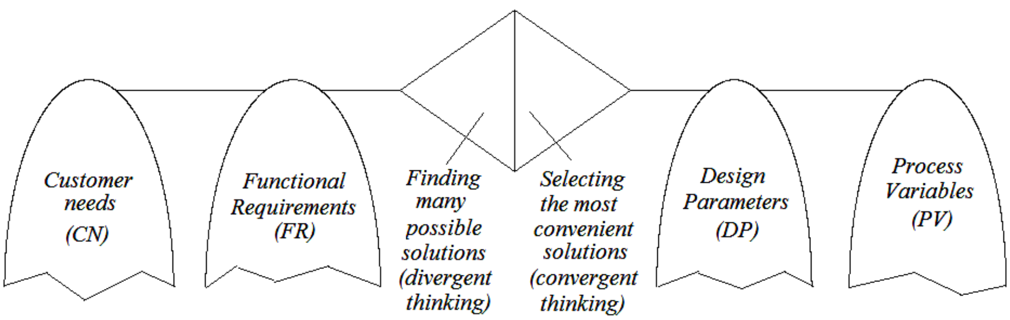

Figure 1. Using creative method for establishing the design parameters.

susceptible to fulfill the functional requirements or just a solution which does not exist, but which will be designed by considering the functional requirements. Indeed, analyzing and combining various versions of the proposed solution components (as specific stages valid when the ideas diagram method is applied), the effects of the divergent thinking could have a beneficial effect in identifying a new or improved solution. Applying criteria of diminishing the number of the versions that could be subsequently evaluated in detail and finally using an adequate selection method, the most convenient solution could be found. This solution could be considered in order to continue the zigzagging activity and to define the final solution.

b) A second way could be applying some changes in the elaboration of the ideas diagram, so it can be used in Axiomatic Design. Aspects specific to Axiomatic Design could be thus introduced and used. The functional requirements could be considered as subassemblies or components or possibilities of obtaining distinct versions of the problem solution. Afterwards, versions of design parameters afferent to each functional requirement could be identified, and, by combining and evaluating the resulted combinations, the most convenient solution could be finally established. This second way of solving the design problem practically combines aspects specific to Axiomatic Design and to applying a creative method by initially considering the ideas diagram.

3 CASE STUDY

In order to obtain a more adequate image about the possibilities of using some principles specific to the ideas diagram to increase the weight of the creative solving of the problem by applying the method of Axiomatic Design, a practical situation is considered. In our research activity, there was formulated the problem of detaching cylindrical parts from a workpiece made of difficult-to-cut material (a high temperature resistant metallic alloy); subsequently, these cylindrical parts had to be affected by certain special treatments and their properties had to be determined by adequate testing methods.

Due to the fact that the workpiece material was characterized by a very low machinability by classical cutting process and also due to necessity to find a machining process able to avoid significant loss of workpiece material, gradually the idea of using the electrical discharge machining was shaped (Figure 2).

One could mention that the electrical discharge machining is a machining method based on the material removal from workpiece as a consequence of developing electrical discharges between closest asperities existing on active surfaces of tool electrode TE and workpiece WP, if a rectilinear low speed work motion v_{TE} is achieved usually by tool electrode TE to workpiece WP (both the tool electrode TE and workpiece WP are connected in an electric circuit of pulse generator PG). By using a tubular tool electrode TE, cylindrical samples was seaming to be obtained in acceptable conditions from workpiece WP (Figure 2a). Indeed, placing the tool electrode TE on the work head of the electrical discharge machine tool and the workpiece WP in a device placed on the machine tool table, one thought that using the vertical work motion v_{TE} of the tool electrode TE, a cylindrical part P could be separated from the workpiece WP. But a first experiment highlighted an unexpected aspect; due to the difficult evacuation of the metallic particles detached from tool electrode and workpiece as a consequence of developing the electrical discharge machining process, during their evacuation from the frontal work gap, these electroconductive metallic particles were facilitating the generation of supplementary electrical discharges (spurious electrical discharges) and, finally, the test piece was characterized by a conical surface, instead of cylindrical one (Figure 2b). It was clear that an improved solution of electrical discharge machining was necessary, in order to diminish the shape errors of the machined parts.

In such a stage, if the first way of applying principles valid in the case of the ideas diagram method within Axiomatic Design method is considered, the customer needs (CNs) could be formulated in the following way:

CN1: detaching a cylindrical part (sample) from a workpiece made of difficult-to-cut material, by a machining process similar to the so-called trepanning process;

CN2: due to the fact that the workpiece material is expensive, it is necessary that machining method generates minimum material loss.

The functional requirement of zero level could be:

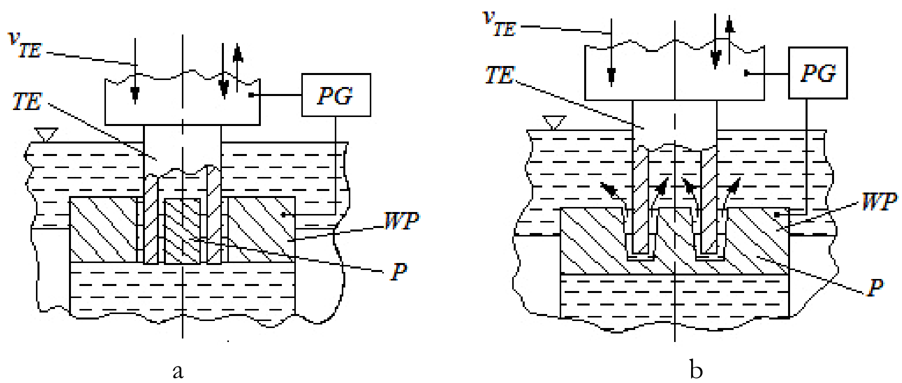

Figure 2. Detaching a part form workpiece by electrical discharge machining with a tubular tool electrode: a – initial thought machining schema; b – obtaining a conical part, due to spurious electrical discharges.

FR0: Detaching a cylindrical part from a workpiece made of difficult-to-cut material, with minimum material loss by machining process.

Taking into consideration the professional experience of the process designer and the unacceptable results of the first experiment, an ideas diagram could be elaborated (Figure 3), immediately after defining the functional requirement of the zero level and considering the functional requirements of first order as subassemblies/components of the desired solution. Subsequently, distinct design parameters could be taken into consideration as distinct possibilities of materializing each functional requirement. These distinct versions of the design parameters are the results of a zigzagging activity.

As one can see, firstly various possibilities of analyzing the machining process were considered and versions for each possibility were identified. Subsequently, the combinations of the above mentioned versions were analyzed and evaluated, so that finally the solution presented in Figure 4, a was thought. Once this solution was established (by using a creative method included in the Axiomatic Design method), the zigzagging activity could be continued in order to optimize also the initial solution.

Considering the versions of subassemblies corresponding to the searched technological solutions in accordance with Figure 3, one may calculate the total number of possible combinations by multiplying the numbers of versions valid for each subassembly; because the subassembly A has 3 versions, B – 3 versions, C – 3 versions, D – 4 versions and E – 3 versions, the total number of combinations N_t is given by:

$$N_t = 3 \cdot 3 \cdot 3 \cdot 4 \cdot 3 = 324 \quad (1)$$

In the second approach of solving the problem, one tried to establish if the stages of elaborating the functional requirements and the design parameters could be adapted or changed by using some principles valid in the case of ideas diagram method.

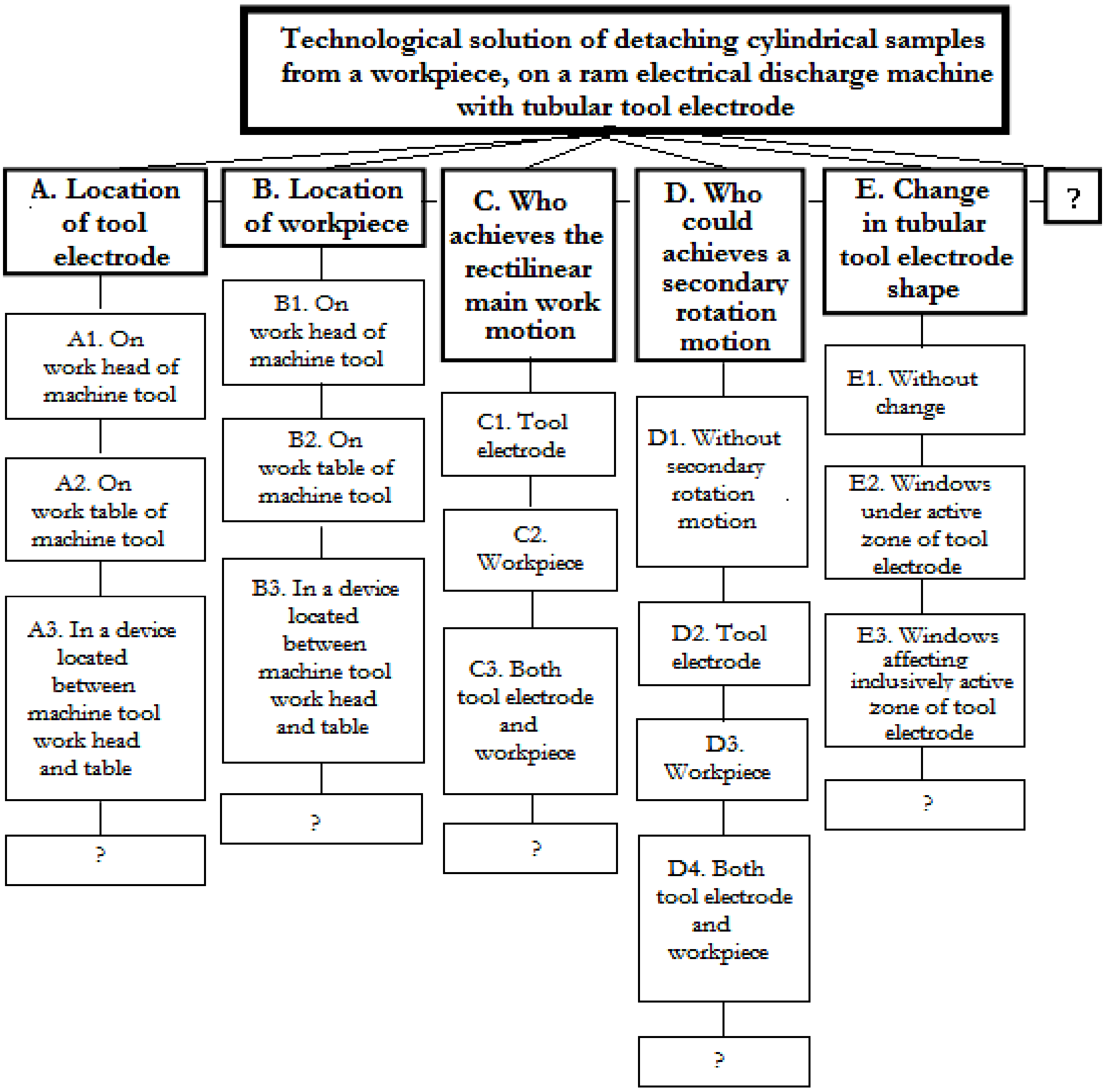

Figure 3. Direct application of principles valid in the case of ideas diagram in searching a technological solution for detaching cylindrical part from workpiece, by electrical discharge machining.

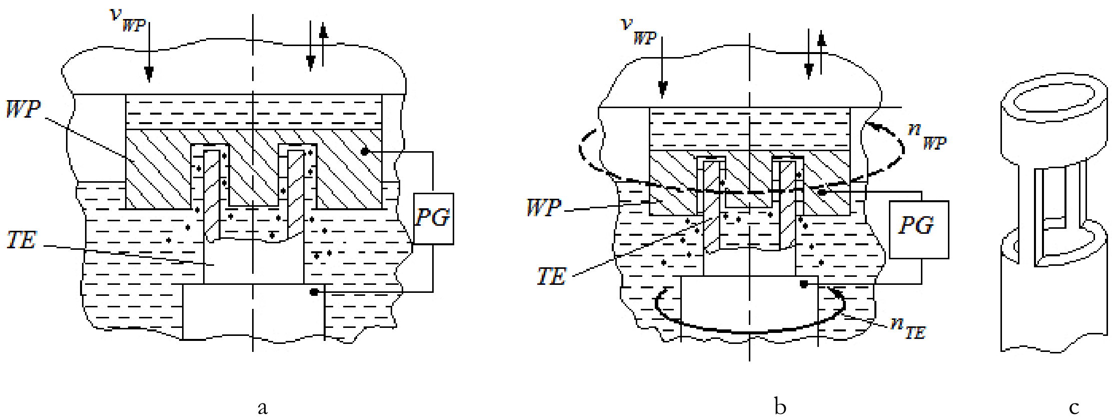

Figure 4. Improved solutions of detaching cylindrical part by electrical discharge machining: a - machining schema without tool electrode rotation motion; b – machining schema by use of a supplementary tool rotation motion; c – tool electrode modified in order to increase the machining accuracy.

Thus, the schema from Figure 5 was elaborated. As one can see, the functional requirements were inscribed in the initial horizontal line of this new graphical representation, instead of the so-called subassemblies or possibilities of analyzing an initial hypothetic solution from the case of ideas diagram. At their turn, each version of a design parameter was symbolized by a Latin small letter (a, b, c etc.) placed immediately after the symbol corresponding to a certain design parameter (DP1, DP2 etc.).

To each functional requirement FR, various design parameters (DPs) were attached, along a vertical line; each design parameter received a code including capital letters corresponding to design parameter and a number which is the serial number allocated to a certain functional requirement.

Among the possible combinations of the design parameters, at least some of them could be convenient for problem solving. In order to have a diminished number of problem solutions necessary to be examined in detail, various methods (for example, methods of value analysis) could be applied; an example of applying such a method was presented in [Slătineanu *et al.*, 2009].

Analyzing the combinations of various versions of the subassemblies included in ideas diagram from Figure 3, one found as advantageous, from the point of view of machining accuracy, the following three combinations:

- A2B1C2D1E1; this means to place the tool electrode on the work table of machine tool (A2) and the workpiece on machine tool work head (B1), the work motion being materialized by workpiece (C2), without supplementary work motions (D1) and using a classical tubular tool electrode (E1). One can see that in this case (Figure 4a), the metallic particles detached from the workpiece and the tool electrode (as a consequence of developing electrical discharge machining process) will be more efficiently removed from the space between electrodes under the action of the gravitation. As a consequence, the number of the spurious electrical discharges diminishes and a higher machining accuracy could be obtained (the conicity of the machined surface could be significantly reduced);

- A2B1C2D2E1; this solution involves to place the tool electrode on the work table of machine tool (A2) and the workpiece on machine tool work head (B1), the work motion being materialized by workpiece (C2), but using a supplementary rotation motion of the tubular tool electrode (D2) and a classical tubular tool electrode (E1). In such a case, in addition to the graphical representation from Figure 4a, a supplementary rotation motion of the tool electrode was included (Figure 4b) and, thus, a higher shape accuracy of the machined surface could be achieved;

- A2B1C2D2E2; this solution differs from the previous solutions by the modified shape of active zone of tubular tool electrode TE (Figure 4c). Thus, if two approximately rectangular windows are included immediately under the active zone of tubular tool electrode, a supplementary decrease of the spurious electrical discharges could occur and a higher machining accuracy could be expected.

One can see that the same three solutions for machining process could be established by adequate selection of the design parameters in accordance with the graphical representation from Figure 5; this means that for the first functional requirement (FR1), the design parameter DP1.b could be preferred, while for the other functional requirements, the selected design parameters could be FR2 – DP2.a, FR3 – DP3.b, FR4 - DP2.a and DP.b, respectively, FR5 – DP5.a and respectively DP5.b.

The second solution was applied and the decrease of the machined surface conicity was confirmed [Slătineanu *et al.,* 2013]; indeed, if for the machining schema from Figure 2*a,* the conicity was of about 0.04, in the case of the machining schema from figure 4, a, the conicity was of about 0.0042.

A more attentive analysis of the solutions suggested by applying the principles valid in the case of ideas diagram method could highlight also other interesting solutions for solving the proposed problem.

4 CONCLUSIONS

In order to obtain new/improved and original solutions, the designer could use creative methods. Over time, various methods aimed at the stimulation of designer creativity were identified and applied. In the case of Axiomatic Design, such a method could be the so-called method of ideas diagram. This method could be applied when the design parameters are established by considering the functional requirements. A second way could be applying some principles valid in the case

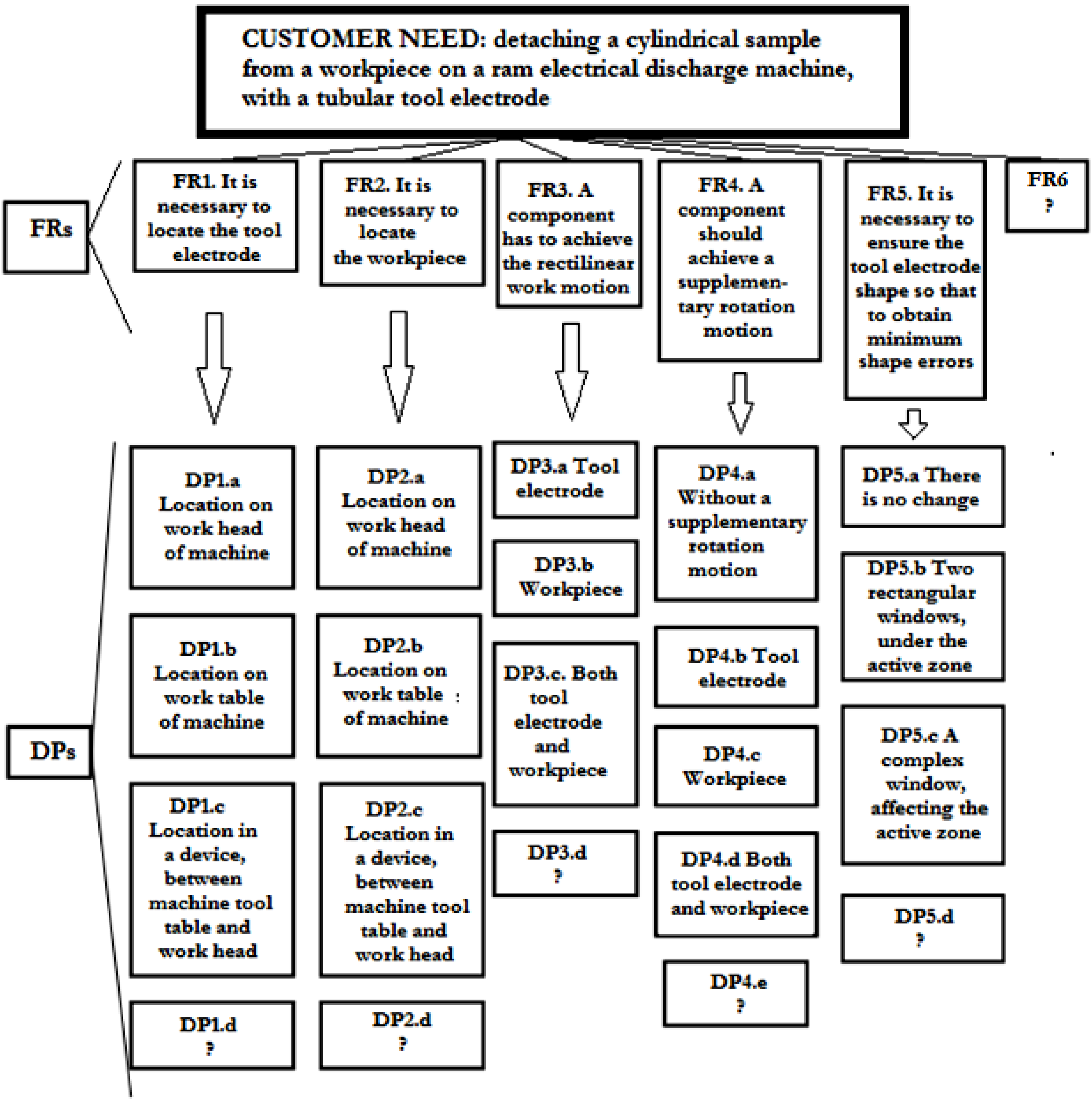

Figure 5. Application of the principle valid in the case of the ideas diagram method in establishing functional requirements and design parameters.

of the ideas diagram method just in the case of establishing the design parameters; for each functional requirement, many versions of each design parameter could be initially identified and subsequently the most convenient design parameters could be established, inclusively by applying an adequate selection method. An application of the two ways of using the principles of ideas diagram elaboration in Axiomatic Design was presented, for a given case when a technological solution for detaching a cylindrical part from a metallic workpiece by electrical discharge machining had to be established. Three possible solutions were identified; essentially, they are based on placing the tubular tool electrode on the electrical discharge machine table, and on the use of a tubular tool electrode having a modified shape of the active zone. proposed problem.

5 AKNOWLEDGEMENTS

The authors are thankful to Professor Mary Kathryn Thompson for useful suggestions and editorial comments.

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