Selection of a Solution When Using Axiomatic Design

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Abstract. Over the years, the importance of the creativity inclusively in the field of design activities was highlighted. In accordance with the opinions of certain researchers, the divergent thinking could contribute to the increase of creative processes efficiency. On the other hand, the axiomatic design method is considered as a method able to stimulate the technical creativity when the problem of designing a mechanical equipment is stated. To increase the efficiency of using the axiomatic design method, the possibility of selecting the most convenient solution among many available solutions could be discussed. The analysis revealed that there are many methods that could be applied in the process of optimum solution selection among many available solutions. In this paper, some aspects concerning the possibilities of using the method of analytic hierarchy process are analyzed, inclusively by considering a case study concerning a device for investigating the universal horizontal lathe rigidity. Afterwards, the first axiom from axiomatic design method was applied to define the selected solution for the approached device.

1 Introduction

In a short definition, *the creativity* could be defined as the ability to generate new ideas or concepts, eventually by applying methods able to help the process of new ideas generation. There is not a unique opinion concerning the person who used firstly the concept of *creativity*. Thus, in a work concerning the of *aesthetics* evolution, the Polish poet and theoretician of poetry Maciej Kazimierz Sarbiewski (1595–1640) is considered as the first person who applied the word "creation" in the field of poetry [1]. On the other hand, the English mathematician and philosopher Alfred North Whitehead is taken into consideration as the inventor of the word "creativity"; he used the concept when defining his metaphysical scheme [2].

In a book published in the Romanian language (I. Căpâlneanu, *Intelligence and creativity*, Editura Militară, Bucharest 1978), there is the opinion that the concept of *creativity* was introduced by Gordon Allport, in 1937 [3].

Over the years, various definitions for the concept of creativity were proposed by the researchers from distinct activity fields. The researchers considered also that there is a certain connection between the significances and applications of the concepts of *creativity* and *divergent thinking*. The last concept (divergent thinking) takes into consideration the generation of multiple alternatives for solving the addressed problem. The distinction between the *convergent thinking* (aiming to identify a single accepted solution) and *divergent thinking* was made by the American psychologist J.P. Guilford; in fact, he used the concepts of *convergent* and *divergent production*, the concepts of convergent and divergent thinking being adopted subsequently.

Generally speaking, *the divergent thinking* is an intellectual process of fluent and operative generation of various solutions for a certain problem. Just from this definition, one could notice the connections between creativity and divergent thinking. In solving technical and engineering problems, it is important to find many solutions in the initial stages of problem-solving, so that subsequently, applying adequate selection methods, the most convenient alternative or alternatives are established.

Such an aspect is also highlighted by a principle of management; this principle shows that when for a strategic problem, a single solution seems to exist, there is a high probability that this solution is not the best one [4]. In accordance with such a principle, the same idea of the significance of the necessity to firstly find many solutions for the addressed strategic problem is stated. Only in a subsequent stage, the selection of the best solution could be approached.

In the last decades, many techniques and methods were proposed and applied to stimulate the technical creativity and some of them take into consideration the

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divergent thinking as a way of finding many solutions for the problem to be solved. More than 190 techniques usable as ways of searching and identifying innovative solutions are highlighted in [5].

The axiomatic design, as a method which could be applied to solve technical problems or problems from other fields of human activity, aims also to efficiently use the specialists' creative abilities [6]. In a set of slides [6] based on the professor Nam Pyo Suh's works [7-9], the significance of the axiomatic design as a method able to stimulate the creativity is highlighted showing that "axiomatic design enhances creativity by eliminating bad ideas early and thus, helping to channel the effort of designers" [6].

In one of the stages of axiomatic design method, there is highlighted the necessity of developing the design parameters because of a zigzagging activity between functional domain and physical domain. In this stage, the designer must search and identify the design parameter for each functional requirement previously established by considering the customer needs.

In the last decades, works describing the contributions of the creativity in applying the axiomatic design were developed and published. Thus, Slocum appreciated that within axiomatic innovation, the creativity has the role of an exact science [10]. As an addition to the axioms defined and applied in the axiomatic design, he took into consideration the technical contradiction axiom, the physical contradiction axiom, and the ideal result axiom, which are used in the TRIZ method; in his opinion, a hybridization of TRIZ method and axiomatic design method could be logical and necessary step.

A possible combination of principles specific to TRIZ method and axiomatic method to enhance the efficient use of the creativity was also discussed [10-18]. Crowell and Gregson used just the concept of *creative axiomatic design*, to highlight the capacity of the axiomatic design to facilitate identification of creative solutions [19]. They proposed a general creativity matrix, in which design parameters *DPs* or process variables *PVs* could be expressed as functions of their behaviors and appreciated that in this way the functional fixation could be avoided.

The objective of this paper was to present the authors' opinions concerning some possibilities of applying firstly the divergent thinking principles in using the axiomatic design method for developing a mechanical device /equipment. Subsequently, using an adequate method of selection (analytic hierarchy process, AHP), a possible optimized solution could be identified.

2 Use of divergent thinking when applying the axiomatic design method

It is well known that the axiomatic design method was proposed by the professor Nam Pyo Suh, in the years '70 of the previous century, when he was working at the Massachusetts Institute of Technology of Boston (U.S.A.). In works published in that period, the professor Suh was referring to the axiomatic approach of manufacturing and of manufacturing systems. The use of axiomatic design method developed gradually and

nowadays there are many economic, technical or other fields where applications of this method were identified. Essentially, the method supposes developing 4 stages, in which the customer needs, the functional requirements, the design parameters and the process variables are gradually established. A first advantage of applying the axiomatic design method is the clearer highlighting of the requirements supposed by the design theme and the continuous connection of the design activity to these requirements.

In applying the method of axiomatic design, one could notice that there is a stage when the designer divides functional requirements *FRs* and establish the design parameters *DPs* able to correspond to each functional requirement. The activity of successive passing from the functional domain to the physical domain is called "zigzagging" and it is expected that during this activity, new or at least improved solutions for the design parameters could be identified so that finally the desired equipment could be characterized by certain original and possible inventive aspects.

To operatively identify the adequate answer for each functional requirement, the designer could limit his searching activity to the first found solution; this means that a convergent thinking way could be preferentially accessed by the designer (Fig. 1).

To increase the weight of divergent thinking method – appreciated as a more able to generate creative solutions, one could take into consideration to search if there are techniques and methods able to increase the possibilities of applying divergent thinking way during the zigzagging process.

The analysis of this problem could lead to two possible approaches:

1) A first approach could take into consideration the applying of divergent thinking for each design parameter. This could mean to firstly search many design parameters for each functional requirement and only later to select those considered as more convenient. This way seems to need a high volume of efforts and it does not take into consideration the image of the entire desired assembly/equipment. For example, problems could
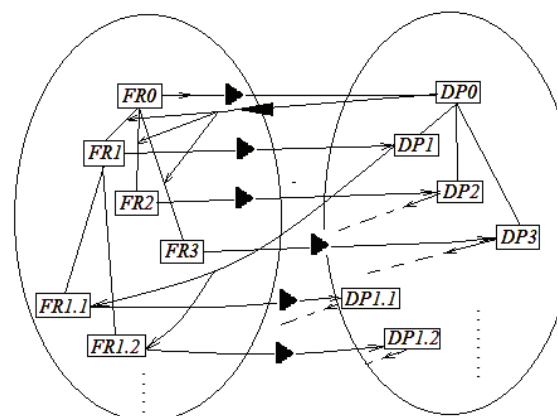

Fig. 1. Possibilities of applying convergent thinking when using functional requirements *FRs* to define each design parameter *DP* (convergent thinking process was highlighted by the symbol ▶).
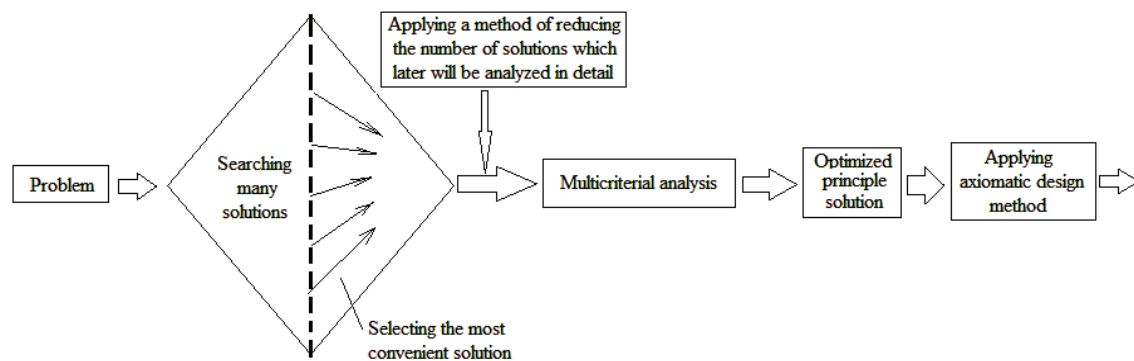
Fig. 2. Applying the divergent thinking method in association with a method of reducing the number of solutions which will be later analyzed in detail and a method of multicriterial analysis, respectively.

appear in this case in assembling the design parameters in the desired general solution;

2) Identifying a possible searching way which could be able that just from beginning to integrate all the design parameters and searching for the convenient solutions for all functional requirements. Such a way could ensure the use of divergent thinking, but it could be more operative and just from the beginning, the entire desired assembly could be considered. A possible solution corresponding to such a way of solving the design problems could be found in the so-called multicriterial analysis or optimizing the selection by means of multicriterial analysis (Fig. 2). A disadvantage of this method could be introduced by the fact that the zigzagging activity diminishes and the probability of identifying optimized solution for each design parameter decreases also.

One must mention that if the convergent thinking supposes a continuous narrowing of the investigated field, by removing the solutions considered as not or less convenient, the applying of the divergent thinking involves practically two distinct stages, a first stage in which the designer efforts are focused on searching many solutions for the addressed problem and a second stage, when practically the convergent thinking is applied.

In a paper published in 2005, Coelho et al. analyzed the use of quality function deployment by adopting the axiomatic design principles [20]. They concluded that the quality function deployment could be applied to improve the existing designs, but in association with the axiomatic design principles, and a faster design process of new solutions is possible.

In a master thesis defended in 2013, Shi showed that the combination of several basic level concepts from the detail design parameters corresponding to the axiomatic design could increase the creativity by highlighting more possible design solutions [21]. He appreciated that the selection of a certain design concept could be achieved by using the axiomatic design ontology Foley and Cochran considered that the axiomatic design is an ontology able to facilitate the representation of the manufacturing system design decomposition in a

knowledge interchange by means of a web ontology language and certain software tools [22].

3 Methods of optimization

As above mentioned, to ensure the use of the most convenient solution able to be developed by using the axiomatic design method, a so-called *method of selecting optimal version* for an object, an equipment or a process could be identified and applied. Since usually the desired solution should correspond to many requirements, a method belonging to the group of *multicriterial optimization* could be preferentially applied.

Nowadays, there are some such methods of multicriterial optimization with a larger or narrower use: for example, one could take into consideration the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), the Analytic Hierarchy Process (AHP), the Analytic Network Process (ANP), the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), the Multi-Objective Optimization on the basis of Ratio Analysis (MOORA), the elimination and choice expressing reality (in French, ELimination Et Choix Traduisant la REalité, ELECTRE), the method of utilities etc. [23-25].

The last decades showed an extended use of the AHP method; this method was applied in the research presented in this paper to select the most convenient version able to optimally solve a design problem.
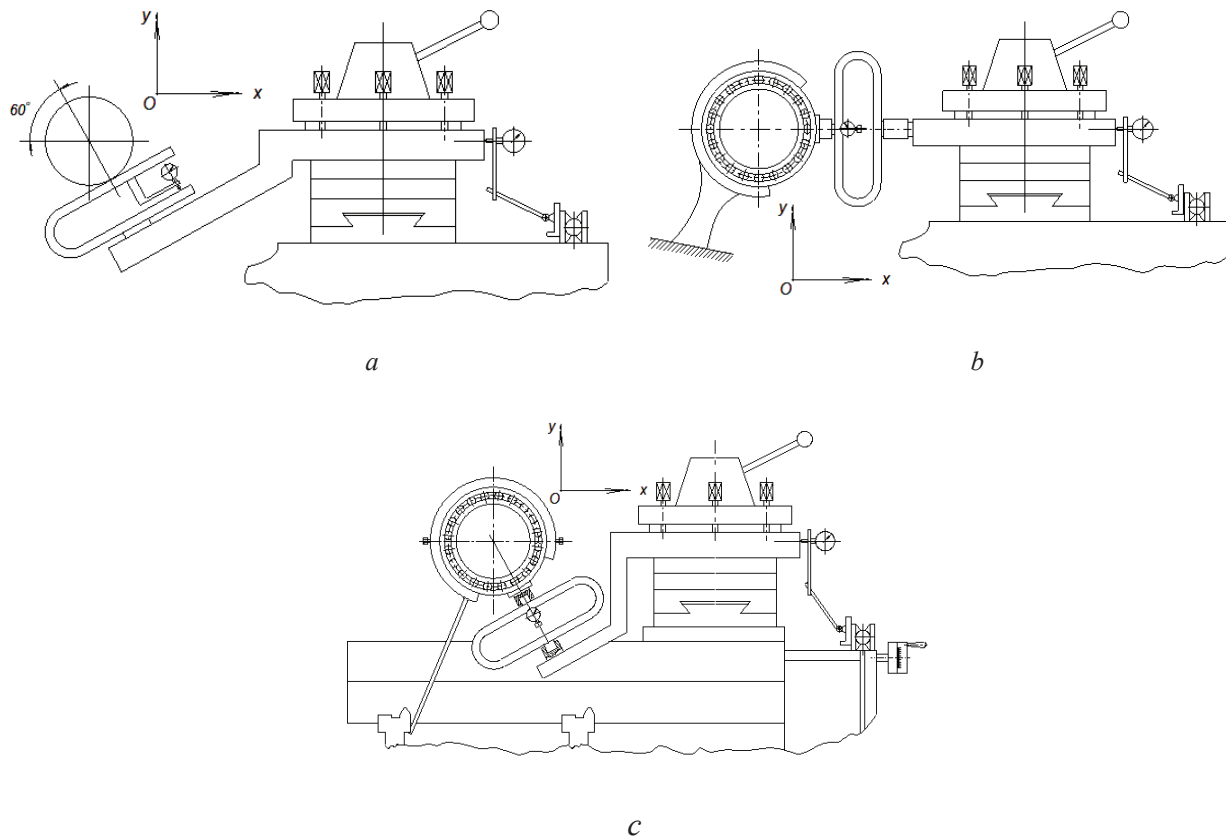
Fig. 3. Versions of a device for evaluating the universal lathe rigidity: (*a*) device for evaluation of static rigidity; (*b*) device for evaluation of the rigidity using the rotation of the lathe main shaft and a system for loading along the axis *Ox*; (*c*) device for evaluation of the rigidity using the rotation of lathe main shaft and a system for loading along two axes, *Ox* and *Oy*.

4 Use of AHP method in selecting the most convenient alternative

Let take into consideration the problem of selecting the device which could be used for the study of the rigidity that characterizes a medium size universal horizontal lathe. When trying to generate the functional requirements and the design parameters corresponding to such a device, the alternatives presented in Figure 3 should be to be taken into consideration for a more detailed analysis. The three considered versions are the following:

1. The alternative *A1*, based on the use of a device recommended in an older regulation for the study of *static rigidity* (Figure 3, *a*): essentially, this device supposes the use of a bar fixed in the universal chuck and in the live center. Using this device, a loading like those corresponding to a transversal turning process is generated. To calculate the lathe static rigidity, the loading force is measured by means of a dynamometer, while the elastic displacement of the tool holder along the *Ox* conventional axis is determined by means of a dial gauge;

2. The alternative *A2*, able to load the technological system with a force directed only along the direction *Ox*, but taking into consideration the rotation of the bar clamped in the universal chuck and in the live center. To ensure the loading just during the bar rotation process, a bearing could be placed on the bar, and the dynamometer takes contact with a bush placed on the bearing external ring (Fig. 3, *b*). The alternative is closer to the real use of the lathe, taking into consideration the bar rotation, but using only the loading along a single axis (*Ox*);

3. The third alternative, *A3*, facilitates the bar rotation, but taking into consideration a system loading along two axes, *Ox* and *Oy* (Fig. 3, *c*).
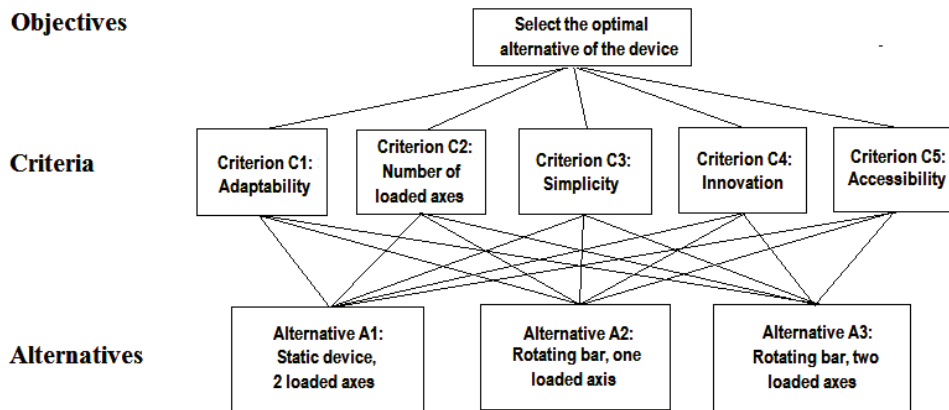
Fig. 4. Applying the AHP method to optimize the principle solution in the case of the device for investigating the lathe system rigidity (in accordance with [26]).

Table 1. Results of comparing the evaluation criteria.

A is more important than B?				Situation of equality	How many times is it important?								
A	or		B	1	2	3	4	5	6	7	8	9
X Adaptability	or		Number of controlled axes		X								
X Adaptability	or		Simplicity	X									
Adaptability	or	X	Innovation			X							
X Adaptability	or		Accessibility		X								
X Number of controlled axes	or		Simplicity	X									
Number of controlled axes	or	X	Innovation		X								
X Number of controlled axes	or		Accessibility		X								
Simplicity	or	X	Innovation					X					
X Simplicity	or		Accessibility	X									
X Innovation	or		Accessibility			X							

The selection of the most convenient solution could be based on the use AHP method. In accordance with the stages specific to this method, its main principles could be illustrated on the base of graphical representation included in Figure 4. The main components of this graphical representation are the design objective, the selection criteria and the alternative for solving the design problem.

There are many criteria that could be used in the case of selecting a device for lathe rigidity evaluation, but in the analyzed example, only 5 such criteria were retained:

- Criterion *C1*, referring to the degrees of closeness to the real turning conditions; the short name of this criterion will be *adaptability*;
- Criterion *C2*, which takes into consideration the number of axes along which the system is loaded;
- Criterion *C3*, highlighting the constructive *simplicity*;
- Criterion *C4*, which considers the level of *innovation*;
- Criterion *C5*, based on the possibility of manufacturing or acquisition of the device components (*accessibility*).

In the first stage, these criteria are compared each other by means of a scale offering 9 degrees of evaluation, among which there are: 1 when two criteria could be considered as of equal importance, 3 when compared with the other, a criterion is considered of moderate importance, 5 – of great importance, 7 - of very big importance, 9 - of extreme importance, and 2, 4, 6 and 8 are considered as intermediate evaluation, between two of the above-mentioned degrees [26].

The results obtained in applying comparison of the criteria were included in table 1.

The information from table 2 could be written as a decision matrix [*A*] having the aspect from the relation (1):

$$
Decision\ matrix\ [A] = \begin{array}{c} \\ C1 \\ C2 \\ C3 \\ C4 \\ C5 \end{array} \begin{array}{ccccc} C1 & C2 & C3 & C4 & C5 \\ \begin{bmatrix} 1 & 2.00 & 1.00 & 0.33 & 2.00 \\ 0.5 & 1 & 1.00 & 0.50 & 2.00 \\ 1.00 & 1.00 & 1 & 0.20 & 1.00 \\ 3.00 & 2.00 & 5.00 & 1 & 5.00 \\ 0.50 & 0.50 & 1.00 & 0.20 & 1 \end{bmatrix} \end{array} \quad (1)
$$

The decision matrix [*A*] could also be written including the sum of the numbers corresponding to each column, as shown in relation (2).

$$
Decizion\ matrix\ [A] = \begin{bmatrix} 1 & 2.00 & 1.00 & 0.33 & 2.00 \\ 0.5 & 1 & 1.00 & 0.50 & 2.00 \\ 1.00 & 1.00 & 1 & 0.20 & 1.00 \\ 3.00 & 2.00 & 5.00 & 1 & 5.00 \\ 0.50 & 0.50 & 1.00 & 0.20 & 1 \end{bmatrix} \quad (2)
$$
$$
6 \quad 6.5 \quad 9 \quad 2.23 \quad 11
$$

The normalized decision matrix [*A_n*] corresponding to the previous decision matrix [*A*] could be defined by dividing each matrix element from a certain column by the sum of elements (relation (3)).

$$
[A]_n = \begin{bmatrix} 0.16 & 0.30 & 0.11 & 0.14 & 0.22 \\ 0.08 & 0.15 & 0.11 & 0.22 & 0.22 \\ 0.16 & 0.15 & 0.11 & 0.08 & 0.11 \\ 0.48 & 0.30 & 0.55 & 0.44 & 0.33 \\ 0.08 & 0.07 & 0.11 & 0.18 & 0.11 \end{bmatrix} \quad (3)
$$

The priority vector w_c corresponding to the selected criteria could be written as a column matrix containing elements obtained as sums of the elements included in each line of the previous matrix (relation (4)).

$$
w_c = \frac{1}{5} \begin{bmatrix} 0.16+0.30+0.11+0.14+0.22 \\ 0.08+0.15+0.11+0.22+0.22 \\ 0.16+0.15+0.11+0.08+0.11 \\ 0.48+0.30+0.55+0.44+0.33 \\ 0.08+0.07+0.11+0.18+0.11 \end{bmatrix} =
$$
$$
= \frac{1}{5} \begin{bmatrix} 0.93 \\ 0.75 \\ 0.61 \\ 2.10 \\ 0.45 \end{bmatrix} = \begin{bmatrix} 0.181 \\ 0.149 \\ 0.123 \\ 0.457 \\ 0.091 \end{bmatrix} \quad (4)
$$

The last column matrix (the priority vector w_c) offers information about the order of the applied criteria and considering percent values: 1. Criterion *C4* (45.7 %); 2. Criterion *C1* (18.1 %); 3. Criterion *C2* (14.9 %); 4. Criterion *C3* (12.3 %); 5. Criterion *C5* (9.1 %).

On the base of the above-mentioned values, one can determine *the principal Eigen value* λ_{max} (relation (5)), the consistency index *CI* (relation (6)), and the consistency ratio *CR* (relation (7)).

$$
\lambda_{max} = 0.181 \cdot 6 + 0.149 \cdot 6.50 + 0.123 \cdot 9 +
$$
$$
+ 0.457 \cdot 2.23 + 0.091 \cdot 11 = \quad (5)
$$
$$
= 1.086 + 0.9685 + 1.107 + 1.019 + +1.001 == 5.176
$$

$$
CI = \frac{\lambda_{max} - n}{n-1} = \frac{5.176 - 5}{4} = 0.044 \quad (6)
$$

$$
CR = \frac{CI}{RI} = \frac{0.044}{1.12} = 0.04040 = 3.92\ \% < 10\ \% \quad (7)
$$

One could notice that the consistency ratio *CR* is lower than 10 %, and this means that the inconsistency could be appreciated as acceptable [26]. In a way, like that above presented, the components of the priority vectors could be determined for each of the three alternatives *A1*, *A2* and *A3* and by means of each of the criteria *C1*, *C2*, *C3*, *C4*, and *C5*; the results are presented in Table 2. Taking into consideration the results included in the first 6 columns from Table 2, the general composite order weights for each alternative could be determined:

$$
A1 = 18.1 \cdot 8.23 + 14.9 \cdot 40.5 + 12.3 \cdot 54.0 + 45.7 \cdot 9.5 + 9.1 \cdot 54.0
$$
$$
= 148.96 + 603.45 + 664.2 + 434.15 + 491.4 = 2342.16 =
$$
$$
= 23.42\ \%
$$
$$
(8)
$$

$$
A2 = 18.1 \cdot 31.50 + 14.9 \cdot 11.4 + 12.3 \cdot 29.7 + 45.7 \cdot 25.0 +
$$
$$
+ 9.1 \cdot 29.7 = 570.15 + 169.86 + 365.31 + 1142.5 + 270.27 =
$$
$$
= 2518.09 = 25.18\ \% \quad (9)
$$

$$
A3 = 18.1 \cdot 60.26 + 14.9 \cdot 48.1 + 12.3 \cdot 16.3 + 45.7 \cdot 65.5 + 9.1 \cdot 1
$$
$$
6.3 = 1090.706 + 716.69 + 200.49 + 2993.35 + 148.33 =
$$
$$
= 5149.566 = 51,49\ \%
$$
$$
(10)
$$

The values of the general composite weights were included in the penultimate column from Table 2; in the last column, the position of each alternative is

Table 2. Evaluation of each alternative by means of each criterion.

Criterion	*C1*	*C2*	*C3*	*C4*	*C5*	General composite weight	Order
Criterion weight **Alternative**	**0.181**	**0.149**	**0.123**	**0.457**	**0.091**		
A1	8.23 %	40.5 %	54.0 %	9.5 %	54.0 %	23.42 %	3
A2	31.5 %	11.4 %	29.7 %	25.0 %	29.7 %	25.18 %	2
A3	60.26 %	48.1 %	16.3 %	65.5 %	16.3 %	51.49 %	1
Sum	99.99 %	100 %	100 %	100 %	100 %	100.09 %	

highlighted. One could notice that if all the criteria are considered, the most convenient alternative is the alternative *A3*, followed by the alternative *A2* and *A1*, respectively, since 51.49 %>25.18 % >23.42 %.

The calculations above presented were achieved by means of the software presented in [22]; let us notice that this software allows an easy change of the numerical values proposed when comparing criteria or alternatives, up to the moment when the consistency could be considered as acceptable.

5 Developing selected alternative by means of the axiomatic design

Once established the most convenient alternative, the stages corresponding to the application of the first axiom from the axiomatic design method could be used [8, 27]. In this way, the information included in table 3 was obtained. One considered that during the process of zigzagging activity developed to define the solution for the device for investigating the lathe system rigidity, a faster selection of a certain solution was possible by using the AHP method was applied. Subsequently, the solution was finalized using the design matrix from the axiomatic design method.

One could see that even the matrix corresponding to the device is similar to an uncoupled matrix; there is a functional requirement that, in this initial stage, is materialized by means of two design parameters, namely by the dynamometer and the dynamometer nut. Of course, some improvements could be taken into consideration to finally obtain an uncoupled matrix. The analysis could be continued by trying to minimize the volume of information involved by the design of selected alternative, in accordance with the second axiom from the axiomatic design method.

6 Conclusions

Over the last decades, gradually an opinion in accordance with a certain correlation exists between the human creativity and the divergent thinking was accepted by certain researchers. On the other hand, the axiomatic design method offers a more systematic and optimized way in approaching distinct stages of the design activity. When the design parameters are established by considering the functional requirements of the distinct order, generally the designer is tempted to use preferentially the convergent thinking way. To increase the probability of finding new and improved technical solutions, before establishing the most convenient alternative, a more intense process of divergent thinking could be recommended. There are various methods applicable firstly to identify many alternatives for solving the approached design problem. When such some alternatives able to solve the design problem are found, the selection of the most convenient one could be also aided by applying a method of optimal selection of a certain alternative. Within the research presented in this paper, there was necessary to design a device for investigating the lathe system rigidity and to obtain an adequate image on the lathe system rigidity. If usually the lathe system rigidity is determined in static conditions, the hypothesis of designing a device able to be used when the lathe main shaft rotates was formulated. Taking firstly into consideration a divergent way of thinking, three distinct alternatives for studying the lathe rigidity were identified. Among the three considered alternatives, a process of selecting the most convenient alternative was applied by means of the analytic hierarchy process method. Subsequently, the axiomatic design method was applied to clearer define the functional requirements and establish some design

Table 3. Matrix that includes the functional requirements and design parameters established in the case of the device for evaluation of the horizontal universal lathe rigidity

Functional requirement of zero level	Functional requirements of the first level	Functional requirements of the second level	DP1.1: Universal chuck and live center	DP1.2: Lathe main shaft	DP2: Dynamometer	DP3.1: Dynamometer nut	DP3.2: Profiled part	DP4.2: Ball Bearing	DP4.2: Step with higher diameter and nut on the control mandrel	DP4.3: External ring placed on the ball bearing including a sleeve	DP4.4: Incomplete additional Ring and lever whose rotation is limited by the longitudinal guide
FR0: design a device for developing a research activity concerning the rigidity of the lathe during the rotation of its main shaft	FR1: Ensure rotation of the lathe main shaft	FR1.1: Fix the control mandrel	X								
		FR1.2: Rotate the control mandrel		X							
		FR2: Measure the force generated in the machining system			X						
	FR3: Generate the system loading along a certain direction	FR3.1: Generate the loading				X	X				
		FR3.2: Establish the loading direction					X				
	FR4: Ensure contact between dynamometer and the lathe main shaft found in rotation	FR4.1: Ensure a nonrotating element placed on the rotating lathe main shaft						X			
		FR4.2: Fix ball bearing on the rotating shaft							X		
		FR4.3: Ensure contact of dynamometer elements and the lathe rotating main shaft								X	
		FR4.4. Ensure rotating complete avoidance of the ring containing the ball bearing									X

parameters. In the future, there is the intention to extend the analysis and defining the components of the selected alternative by means of the axiomatic design method. A device for investigating the lathe system rigidity will be manufactured, to experimentally obtain information concerning the lathe rigidity when the lathe main shaft rotates.

References

1. W. Tatarkiewicz, *A History of Six Ideas: an Essay in Aesthetics* (Neuhoff, The Hague, 1980)

2. S. Meyer, *Introduction: Whitehead Now*. In Handbook of Whiteheadian Process Thought (eds.: M. Weber and W. Desmond, Onto Verlag, Frankfurt / Lancaster, 2008)

3. I. Căpâlneanu, *Intelligence and creativity* (in Romanian) (Editura Militară, Bucharest 1978)

4. I. Ghinea, Buletin de informare tehnico-economică (in Romanian), 2, (1973)

5. Creativity Techniques. A to Z, available: https://www.mycoted.com/Category:Creativity_Techniques, accessed: 3.04.2017

6. 2.882, System design and analysis based in AD and complexities theories (2015), available: http://documentslide.com/documents/axiomatic-intro.html, accessed: 28.03.2017

7. N.P. Suh, *The Principles of Design* (Oxford University Press, New York, 1990)

8. N.P. Suh, *Axiomatic Design: Advances and Applications* (Oxford University Press, New York, 2001)

9. N.P. Suh, *Complexity: Theory and Applications* (Oxford University Press, New York, 2005)

10. M.S. Slocum, available: https://triz-journal.com/ innovation-methods/innovation-triz-theory-inventive-problem-solving/axiomatic-innovation-creativity-exact-science/, accessed : 15.05.2017

11. M.K. Thompson, Proceedings of the 5th International Conference on Axiomatic Design, (2009)

12. D. Mann, TRIZ Journal, June (1999)

13. Y. Borgianni, D. T. Matt, Procedia CIRP, **34**, 1, (2015)

14. S.-T. Uang, C.-L. Liu, and M. Chang, In *"Design, user experience, and usability. Theory, Methods, Tools and Practice"* (ed. A. Marcus), 6770, (Springer, Berlin Heidelberg, 2011)

15. J.R. Duflou, and W. Dewulf, Procedia Engineering, 9, 633 (2006)

16. F. Banciu, I. Grozav, Buletinul AGIR (Romania), 2 (2011)

17. F.V. Banciu, CoSME'16, MATEC Web of Conferences, 94 (2017)

18. K. Yang, 4th International Conference on Axiomatic Design, 2006

19. B. Crowell, P. Gregson, Proceedings of the Canadian Engineering Education Association (2008)

20. A. M. Gonçalves-Coelho, A. J. F. Mourão, Z. L. Pereira, Concurrent Eng-Res A, **13**, 233 (2005)

21. Z. Shi, available: http://tigerprints.clemson.edu/ cgi/viewcontent.cgi?article=2779&context=all_thes es, (2013), accessed: 10.05.2017

22. J.T. Foley, D.S. Cochran, Procedia CIRP, **60**, 175-180 (2017)

23. I.B. Huang, J. Keisler, I. Linkov, Science of The Total Environment, **409**(19), 3578-3594 (2011)

24. C.-L. Huang, K. Kwang sun, *Multiple Attribute Decision Making. Methods and Applications. A State-of-the-Art Survey* (Springer Verlag, Berlin Heidelberg, 1981)

25. A. Mardini, A. Josh, K.M.D. Nor, Z. Khalifa, A. Val pour, Economic Research-Kenosha Australiana, 28(1), 516-571 (2015)

26. K.D. Gospel, http://bpmsg.com/academic/ahp _catchup (2011), accessed: 5.05.2017

27. C.A. Brown, *Elements of Axiomatic Design. A simple and practical approach to engineering design* (Cazenovia, New York, 2006)