ESTABLISHING REQUIREMENTS FOR MECHANICAL EQUIPMENT DESIGN

Laurențiu SLĂTINEANU[1], Oana DODUN[1], Margareta COTEAȚĂ[1], Gheorghe NAGÎȚ[1], Irina BEŞLIU[2]

ABSTRACT: To develop the design activity in the case of a mechanical equipment for a machining process, certain initial conditions should be known and these conditions are sometimes called design requirements. Over the years, various methods were used in to elaborate the design requirements. Within the method of value analysis, better initial information is offered by the product or process functions. When the axiomatic design method is applied, the so-called functional requirements are taken into consideration. In the paper, the value analysis method and the axiomatic design method are used to highlight the design requirements in the case of a polyfunctional minimachine tool. One noticed that if the value analysis method is applied, some functions which are not technical attributes of the product or process are considered, in the case of applying the principles of the axiomatic design method only the requirements that could be materialized by a certain component of the desired product are considered.
KEY WORDS: value analysis method, product functions, axiomatic design method, functional requirements, polyfunctional minimachine tool.

1 INTRODUCTION

It is known that *the industry* is a branch of the material production which involves the changing of natural resources in production means and consumer goods. In connection with such a definition, the product is a material good obtained by a labor process.

The product lifecycle includes all the activities or stages corresponding to a certain product, from the statement of idea of product and up to the disassembling or decomposition of the product, in order to re-use its components. As main phases of the product lifecycle, the followings could be considered (Machac, 2014): 1. Conceive; 2. Design; 3. Realize; 4. Service. If only the subphases of conceiving and designing the product are considered, one could notice the importance of these subphases, due to their influence on the subsequent phases of product existence. Indeed, the manufacturing processes, the proper use of product and its service or repairing activities and just its final disassembling are strongly influenced by the decisions adopted in the initial phases of product life. An efficient design activity means an activity finalized by a product able to maximally meet the utilizing functions, but involving low manufacturing and servicing costs.

[1] Universitatea Tehnică “Gheorghe Asachi” din Iași, Departamentul de Tehnologia Construcțiilor de Mașini, B-dul D. Mangeron, 59A, 700050 Iași, România
[1] Universitatea “Ştefan cel Mare” din Suceava, Departmentul de Mecanică şi Tehnologii, Str. Universităţii 13, 720229 Suceava, România
E-mail: slati@tcm.tuiasi.ro, oanad@tcm.tuiasi.ro, mcoteata@tcm.tuiasi.ro, nagit@tcm.tuiasi.ro, irina.besliu@yahoo.com

On the design activity, many factors exert influence: the clarity of the design objectives, the designer professional level, the possibility of accessing scientific and technical information, the existence of modern design equipment and software etc. If the design target is urgent, the designer has not time enough to consult the solutions found in connection with the design target and he could adopt a known solution, this meaning *a routine solving of the technical problem.*

On the other hand, there are situations when the problem of generating a new or at least an improved solution is formulated; in such a case, the designer could use adequate methods to identify creative solutions. In fact, one could take into consideration *a creative solution of the technical problem.* An innovative solution means an ampler documentation on the design theme, considering many solutions able to correspond to final objective and adequate use of methods of selecting the most convenient solution among many such available solutions.

Within the phases of product design, there is a first subphase which takes into consideration the definition of the product requirements, as they were formulated by the customer, company, market and regulatory bodies’ viewpoints (PLM, 2016).

The formulation of the product requirements is important both for routine design and innovative design, but supplementary arguments highlight the significance of the product requirements formulation in the case of innovative design; in such a case, more attention must be paid to the product requirements formulation, to ensure a certain level of novelty to the future product.

Within the subphase of product requirements formulation, sometimes the designer tries to elaborate the first sketches for the future product. In this way, psychical processes could be initiated in the so-called designer subconscious and these processes could offer to the designer a higher probability of identifying at least improved solutions for the approached technical problem. The authors of this paper are convinced that the elaboration of sketches corresponding to the future product just in the subphase when the design requirements are formulated, could help the designer in developing new or improved solutions for the technical problem.

It is expected that the statement of the functions specific to a certain product or process takes into consideration all the essential aspects susceptible to be used by the designers during their design activity. This means that the significant information necessary in the design process must be rigorously analyzed to be included in the statement of product functions or of the functional requirements.

Over the years, the researchers analyzed the aspects specific to the subphase of product requirements formulation and they observed interesting aspects.

Thus, Ömer Akin and Ipek Özkaya (Akin & Özkaya, 2002) considered that in the field of architecture, sometimes the design errors and failors are determined by a poor requirement specification during both early stages of design and when changes are made. They highlighted the possibilities offered by the computers in design iterations within the initial design stages.

Within this paper, some aspects concerning applying the value analysis method and the axiomatic design method, respectively, are analyzed in the case of necessity of designing a polyfunctional minimachine tool.

2 STATEMENTS OF PRODUCT FUNCTIONS WHEN USING THE METHOD OF VALUE ANALYSIS

In the field of manufacturing, *the value analysis* could be defined as a systematic analysis able to facilitate the identification and selection of the best value alternatives among various designs, materials, processes and systems. The method name highlights the possibility of increasing the product use value, but maintaining or diminishing its cost.

Called sometimes *value engineering* (especially when the concept is applied to new objects), this method involves some essential stages (Ivan Stan, 2003):

a) Developing preparatory activities, this meaning the statement of theme and finally establishing and approving a work plane;

b) Analysis of social necessity;

c) Analysis and evaluation of current situation;

d) Conception or re-conception of the product;

e) Approval of optimal solution;

f) Materializing and controlling the approved proposals.

There are various criteria applied when the product functions are analyzed. Thus, the following criteria (Pugna, 2011) could be taken into consideration: significance (there are main functions and auxiliary functions), possibilities of measuring certain technical dimensions of the object (objective functions and subjective functions), contributions to achieving the value of utilizing (necessary functions and useless functions), the moment when the study is developed (existing functions and new functions), level of generality (specific functions and general or common functions), way of evaluation by the user (main and auxiliary functions or primary and complementary functions).

The value analysis developed in the research activities initiated by Lawrence D. Miles within the General Electric Company, after the second world war. He noticed that the old products could be improved by using new materials. Some aspects specific to the value analysis were connected with the monocriterial analysis by F. Porsche, in the ’30 years of the previous century (Pugna, 2011).

A simplified application of some principles specific to the use of value analysis method in the case of *a polyfunctional minimachine tool* is presented in table 1. As the name of this mechanical equipment highlights, a polyfunctional machine tool must be able to materialize various machining processes, such are turning processes, milling processes, drilling processes etc. (Slătineanu et al., 2016). The problem of designing a polyfunctional minimachine tool was formulated when analyzing the possibilities of using such a minimachine tool in certain specific situations. Thus, a polyfunctional minimachine tool could be used in isolated households when the necessity of manufacturing simple objects could appear. Such a machine tool could be also used within small workshops, when the acquisition of specialized machine tools (lathe, milling machine, drilling machine etc.) could not be efficient. For example, in the case of a workshop attached to a small enterprise and when the

Table 1. Functions corresponding to the polyfunctional minimachine tool elaborated in accordance with the principles of value analysis method

Function code	Function name	Function category if the importance is considered	Function category if the possibilities of measuring functions are considered
A	Overall small dimensions	main	objective
B	Including possibility of achieving turning processes	main	objective
C	Including possibility of achieving milling processes	main	objective
D	Including possibility of achieving drilling processes	main	objective
E	Including possibility of achieving cutting processes	main	objective
F	Ensuring simple operations when changing the machining units	main	objective
G	Needing simple knowledge concerning the machining processes	secondary	subjective
H	Ensuring possibility of clamping workpieces having various shapes	main	objective
I	Ensuring possibility of changing the position of the workpiece	main	objective
J	Ensuring possibility of using a drilling- milling portable machine for driving	main	objective
K	Characterized by an aesthetic aspect	secondary	subjective
L	Ensuring possibility of easy change of machining units	main	objective

frequency of needed machining processes is low, a polyfunctional minimachine tool could be useful and efficient. A polyfunctional minimachine tool could be also used within activities of professional schooling.

In table 1, some essential functions of the polyfunctional minimachine tool were highlighted. The criteria of product importance and of possibilities of measuring the product functions were used to show some aspects specific to the use of the principles of value analysis method.

3 STATEMENTS OF FUNCTIONAL REQUIREMENTS WHEN USING THE AXIOMATIC DESIGN METHOD

On the other hand, the so-called *method of axiomatic design* developed over the last decades. Essentially, this design method takes into consideration two axioms: *1)* The independence axiom, which statues that the product or process functional requirements must be considered as being independent; *b)* The information axiom, which requires that the information necessary to develop the product design activities is minimum.

Four domains are highlighted when the axiomatic design is applied: customer field, functional field, physical field and process field. There are specific rules in identifying and defining the product requirements. Thompson appreciated (Thompson, 2013) that five types of procedural errors could appear when the functional requirements could be defined:

1) Considering a mix of functional requirements with design parameters;

2) Considering a mix of functional requirements with other types of requirements;

3) Considering a mix of functional requirements of the various stakeholders and of the artifact;

4) Considering a mix of the functional requirements of the artifact and of the related systems;

5) Including negative functional requirements.

There is the recommendation that the functional requirements have an imperative character, this meaning that verbs must be used. The elaboration of functional requirements could take into consideration a process of division and ranking, starting from the customer needs. In the case of the above mentioned polyfunctional minimachine tool, the following three customer needs could be formulated:

CN1: polyfunctional machine tool;

CN2: overall small dimensions of the machine tool;

CN3: simple constructive solution.

The last customer need was mentioned to ensure a low price, a simple use, repair and maintenance of equipment.

In such a case, the functional requirement of zero order could be:

FR0: design a simple polyfunctional minimachine tool.

The functional requirements of zero order could be divided in some requirements of first order, which could be:

FR1: ensure a base structure on which various machining units could be placed:

FR2: ensure a possibility of materializing turning processes;

FR3: ensure a possibility of materializing processes of milling and drilling;

FR4: ensure possibility of materializing cutting processes;

FR5: ensure changing the position of the machining unit;

FR6: ensure possibility of clamping the workpiece;

FR7: ensure possibility of moving the workpiece.

FR8: ensure a possibility for supporting long revolution workpieces;

FR9: drive machining unit.

For each of functional requirement of first order, at least one or even many functional requirements of second order could be highlighted:

FR1.1: ensure a base part or subassembly and on

Table 2. Matrix corresponding to the polyfunctional minimachine tool

Line no. 1	Design parameters			Design parameters *DPi*																
2				Design parameters of first level																
3				*DP1:*			*DP4*		*DP3*		*DP4*		*DP5*		*DP6*		*DP7*		*DP8*	*DP9*
4				Design parameters of second level																
5	Functional requirements *FRi*			*DP 1.1*	*DP 1.2*	*DP 1.3*	*DP 2.1*	*DP 2.2*	*DP 3.1*	*DP 3.2*	*DP 4.1*	*DP 4.2*	*DP 5.1*	*DP 5.2*	*DP 6.1*	*DP 6.2*	*DP 7.1*	*DP 7.2*	*DP 8*	*DP 9*
6/1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
7	Functional requirement of zero level	Functional requirements of first level	Functional requirements of second level	Design parameters corresponding to each functional requirement																
8		*FR1*	*FR1.1*	X																
9			*FR1.2*		X															
			FR1.3			X														
10		*FR2*	*FR2.1*				X													
11			*FR1.2*					X												
12	*FR0:* s	*FR3*	*FR3.1*						X											
13			*FR3.2*							X										
14		*FR4*	*FR4.2*								X									
15			*FR4.2*									X								
16		*FR5*	*FR5.2*										X							
17			*FR5.2*											X						
18		*FR6*	*FR6.2*												X					
19			*FR6.2*													X				
20		*FR7*	*FR7.1*														X			
21			*FR7.2*															X		
22		*FR8*	*FR8*																X	
23		*FR9*	*FR9*																	X

which various machining units could be directly placed;

FR1.2: ensure an intermediary part or subassembly for indirectly attaching the machining units;

FR1.3: ensure placing the subassembly for positioning the machining units on the base part or subassembly;

FR1.4: ensure placing and positioning the machining units on the intermediary part or subassembly;

FR1.4: ensure changing the position of machining unit on the intermediary part or subassembly;

FR2.1: ensure rotation of workpiece with various rotation speeds;

FR2.2: ensure placing and moving turning unit on the base part or subassembly;

FR3.1: ensure possibility of developing processes of milling and drilling;

FR3.2: ensure placing the milling and drilling unit on the subassembly for positioning the milling and drilling unit and on the intermediary part or subassembly for indirectly attaching the milling and drilling unit;

FR4.1: ensure the materialization of cutting processes;

FR4.2: ensure placing the cutting unit on the intermediary part or subassembly;

FR5.1: ensure changing the position of the machining unit along a vertical axis;

FR5.2: ensure positioning the machining unit by rotation around a horizontal axis;

FR6.1: ensure a possibility for supporting the device for clamping the workpiece;

FR6.2: ensure possibility of clamping various workpieces.

FR7.1: ensure possibility of moving the table along the base part or subassembly;

FR7.2: ensure a possibility for moving the table along a direction perpendicular on the direction of the base part or subassembly.

FR8: ensure supporting long revolution surface shaped workpieces;

FR9: drive machining unit.

In a more detailed analysis and application of the principles specific to the axiomatic design method, new divisions and ranking of functional requirements could be added.

To each of the above mentioned functional requirement of second order, adequate design parameters must be identified. Thus, for example, the following design parameters of second order could be taken into consideration:

DP1.1: block or assembled bed;

DP1.2: vertical column;

DP1.3: guide on the bed;

DP2.1: turning unit;

DP2.2: slide for placing and moving the turning unit on the bed;

DP3.1: milling unit;

DP3.2: support for the milling and drilling unit;

DP4.1: cutting unit;

DP4.2: support for the cutting unit;

DP5.1: guide and slide for moving the machining unit along a vertical axis;

DP5.2: guide and slide for angular positioning of the machining unit on the vertical column;

DP6.1: table supporting the device for clamping the workpiece;

DP6.2: vice for clamping the workpiece;

DP7.1: slide for moving the table along the base part or subassembly;

DP7.2: guide and slide for moving the table along a direction perpendicular on the main direction of the bed;

DP8: tailstock assembly;

DP9: portable drilling-milling machine.

Taking into consideration the above-mentioned components of the polyfunctional minimachine tool, the matrix corresponding to it was elaborated (table 2).

In accordance with the independence axiom from the axiomatic design method, the number of the functional requirements *FRi* must be equal to the number of design parameters *DPi* and this means that the design matrix must be a square matrix.

If one design parameter could be assigned to each functional requirement, the square design matrix is *a diagonal matrix* and this could be considered as a convenient design matrix (ideal design). Applying the principles specific to the axiomatic design method, the schematic representation of the polyfunctional minimachine tool from figure 1 was elaborated.

4 CONCLUDING REMARKS

The design of a mechanical equipment or of a manufacturing process involves the knowledge and the analysis of the design initial conditions. Such conditions are considered as product functions within the value analysis method and functional

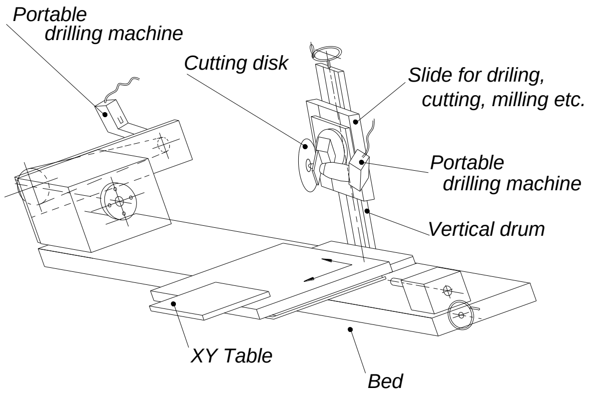

Figure 1. Polyfunctional minimachine tool including a cutting unit

requirements in the case of axiomatic design method. Even there are common aspects in defining the design requirements in the above mentioned two design methods, there are also some differences. To highlight these differences, a succinct analysis was developed, by taking into consideration the case of a polyfunctional minimachine tool. If in the case of applying the value analysis method some aspects which are not technical are considered, in the case of the axiomatic design method only the design requirements are able to be materialized by a certain component of desired product (only design parameters) are taken into consideration. In the future, there is the intention to continue the analysis of ways in which various design methods take into consideration the so-called initial design requirements.

5 REFERENCES

►Akin, O., Özkaya, I. (2002). *Models of Design Requirement*, available at: http://papers.cumincad.org/data/works/att/ddssar0202.content.pdf. Accessed: 2016-11-18

►Machac, J. (2014). *Risk management in early product lifecycle phases*, International Review of Management and Business Research, vol. 3, no. 2, 1151-1162

►*PLM – a different concept of lifecycle management* (2016). Poznan University of Technology. M. Sc. Programmes. Product Engineering. Field of study: Mechanical Engineering. Available at: http://www.prodeng.put.poznan.pl/LCM/LCM6.pdf. Accessed: 2016-11-15

►Pugna, A. (2011). *Analiza, ingineria și managementul valorii.* Available at: www.mpt.upt.ro/doc/curs/pugna/AIMV/Capitolul_2_AIMV.pptx. Accessed: 2016-11-29

►Stan Ivan, F.E. (2003). *Analiza și ingineria valorii - Suport de curs și aplicații*. Available at: http://elth.ucv.ro/student1/Cursuri/Stan%20(Ivan)%20Felicia/Analiza%20si%20ingineria%20valorii/Suport%20curs%20AIV/suport%20curs%20si%20aplicatii%20aiv.pdf. Accessed: 2016-11-29

► Slătineanu, L., Dodun, O., Coteaţă, M., Coman, I., Manole, I., Gika, C.V. (2016). *Requirements statement in product design.* Communication within the conference IManEE 2016, September 23-25, 2016 Kallithea Chalkidiki, Greece

► Slătineanu, L., Dodun, O., Coteaţă, M., Nagîţ, G., Rîpanu, M.I., Beşliu, I. (2016). *Identifying possible solutions for a polyfunctional minimachine tool by means of ideas diagram method*, Proceedings in Manufacturing Systems, vol. 11, no. 3, 159–164

►Thompson, M. K. (2013). *A classification of procedural errors in the definition of functional requirements in axiomatic design theory*. Proceedings of ICAD2013. The Seventh International Conference on Axiomatic Design, Worcester – June 27-28 ICAD-2013-16

6 NOTATION

The following symbols are used in this paper:
FR = functional requirement;
DP = design parameter.