

Requirements statement in product design

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Abstract. One of the activities corresponding to the product design and development refers to clarifying the requirements necessary to be fulfilled by the final product. There are distinct opinions concerning the ways in which these requirements could be formulated and applied. The paper presents the results of a succinct analysis aiming to highlight the developing of product requirements in the case of applying the value analysis method and the axiomatic design method, respectively. The way in which the requirements are formulated in the case of a patent application is also considered. Results of the study were applied in the cases of designing some mechanical products.

1. Introduction

In the life cycle of a product, there is a stage when its design is necessary. There are different ways of defining the product design; here, we will consider that the product design includes the activities developed after a certain product idea is well contoured and up to the moment when all the drawings are definitively achieved. Similar aspects could be considered about the technological process design, in such a case the activities being finalized by technological documentation.

In order to meet the objectives for which the product is designed, the substage of adequate requirements formulation could be taken into consideration. There are also distinct opinions of researchers about the ways in which the requirements specific to a certain product could be formulated and developed.

Thus, a certain guide could be constituted by the way in which the product functions are established in accordance with *the value analyses method*. Some decades ago, Lawrence Miles, Jerry Leftow, and Harry Erlicher, when they were working for General Electric, defined the value analysis as a method of functional systemic analysis of the product, in order to diminish the manufacturing costs, by removing the costs which were not contributing to the product use. Over the time, the value analysis developed gradually and new techniques were identified in order to solve various problems.

Leber et al. investigated the usefulness of two methods of innovative management, namely the value analysis and the conjoint analysis that could be applied in order to design a new product [4]. They concluded that an objectively determined value of a product can have a significant role in obtaining a product of interest for customer or user.

Crow formulated a set of considerations concerning the possibilities of using a function analysis system technique as an analysis tool [1]. He proposed a methodology of applying a value improvement process, by using the functional analysis system technique as a communications vehicle and a tool for addressing the stage of the creative phase in the activities of product design.



On the other hand, in the last decades, the validity of the principles corresponding to the so-called *axiomatic design* was proved. This design method considers that there are two fundamental axioms, namely the independence axiom, which needs the independence of functional requirements necessary to be met by the product, and the axiom of information, which stipulates the necessity of minimizing the quantity of information used during the design activities [6]. When applying the axiomatic design method, after the customer needs are defined, the functional requirements must be formulated.

Thompson (2013) showed that a method of structuring the process of formulating the requirements could be considered [7]. She appreciated that a system of classifying the functional requirements could be used, in order to diminish the probability of excluding one or more key stakeholders during the design activity.

Thompson developed also a set of considerations concerning the classification of procedural errors possible to appear in the process of defining the functional requirements in accordance with the axiomatic design theory. She mentioned five classes of such procedural errors met in the definition of the functional requirements both by novice and expert designers [8].

Within this paper, the problem of designing certain mechanical devices/products/processes was formulated and the ways in which the requirements specific to these devices were investigated; the paper presents the results of this investigation.

Table 1. Functions corresponding to the device tap elaborated in accordance with the requests specific to 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	Adaptable to the most of classical sink faucets	main	objective
B	Acted by foot	main	objective
C	Needs an acting force achievable by foot	secondary	objective
D	Including a connection between the tap and the acting by foot subassembly	secondary	objective
E	Ensuring protection of the components against the corrosive action of the environment	secondary	objective
F	Ensuring force for closing the tap	secondary	objective
G	Ensuring ease use and maintenance	secondary	objective
H	Characterized by an aesthetic aspect	secondary	subjective
I	Characterized by low volume	secondary	objective

2. Aspects specific to establishing the product functions in the case of using the value analysis method

The so called nomenclature of product functions must include only the necessary functions. Two rules must be applied when the product functions must be defined [5]:

1) A function is considered as useful if it adds value of usage to the product and if it could exist in an independent way in relation to the other functions;

2) In order to establish if a certain function is not useful for the product, the rule of function removal could be applied. If a product function is removed and the product utility is not affected, this means that the function is not useful.

If the possibilities to measure a function are considered, one can notice that a function could be *objective*, when it can presents measurable dimensions by means of one or many well determined measure units and *subjective*, respectively, when it is not measurable and it could express a certain affective state.

If the importance of a function is taken into consideration, one can mention that there are also *main functions*, that define the objectives that must be met by the product, and *secondary* or *auxiliary functions*, that ensure the conditions for fulfilling the main functions and that indirectly contribute to the achieving the product total value of using the product.

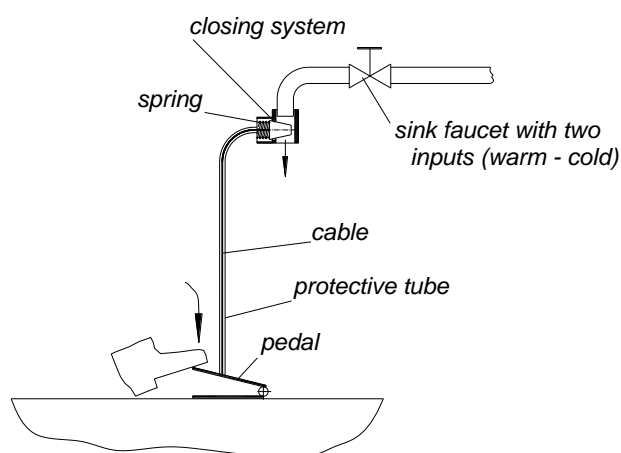


Figure 1. Schematic representation of a water saving faucet identified by considering the product functions and the rules valid in the case of applying the values analysis method.

There is the risk of developing confusions between the *functions* and *social needs*, between functions and *functional characteristics*, between functions and *the technical solutions for achieving the functions*, between the *main functions* and *the secondary or auxiliary functions* [5].

The above mentioned rules were applied in the case of a faucet with water saving. It is known that usually, the faucet is maintained open even when the water is not used and this could mean a waste water. If the faucet itself or a device added to the classical tap could be acted by foot only when the water is necessary, a certain water saving could be achieved.

The product identified functions corresponding to this faucet or device faucet were placed in the table 1, where the qualifier objective/ subjective was also included.

On the base of the functions included in the table 1, the water saving faucet whose schematic representation is presented in Figure 1 was identified. One can see that a way in which an additional device could be added to the common faucet was identified, in order to save the water consumption by acting a pedal only when the water must really flow.

3. Aspects specific to formulation of the functional requirements in the case of applying the axiomatic design method

In the case of using the axiomatic design method, four domains could be initially identified: customer domain, where the customer needs are highlighted, functional domain, where functional requirements are mentioned, physical domain, where the design parameters are specified and process domain, in which the process variables must be showed (Fig. 3).

The errors met frequently when defining the functional requirements could be the following [7]: a) not all the stakeholders are identified; b) One or more classes of stakeholders are wrongly emphasized or excluded; c) One or more categories of requirements are wrongly mentioned or excluded.

In the present paper section, the problem of identifying a technological solution for obtaining threads with variable pitch necessary in a doctoral research is taken into consideration. One can notice that the researcher could be considered as customer. The customer need could be the design and developing a technological solution adaptable on one of the universal machine tools found in the research laboratory, in order to study the possibilities of obtaining threaded surfaces with variable pitch by cutting.

In accordance with this customer need, the main functional requirement could be formulated in the following way: design a technological solution able to allow obtaining and studying the threaded surfaces with variable pitches and distinct characteristics on a universal machine tool found in the research laboratory.

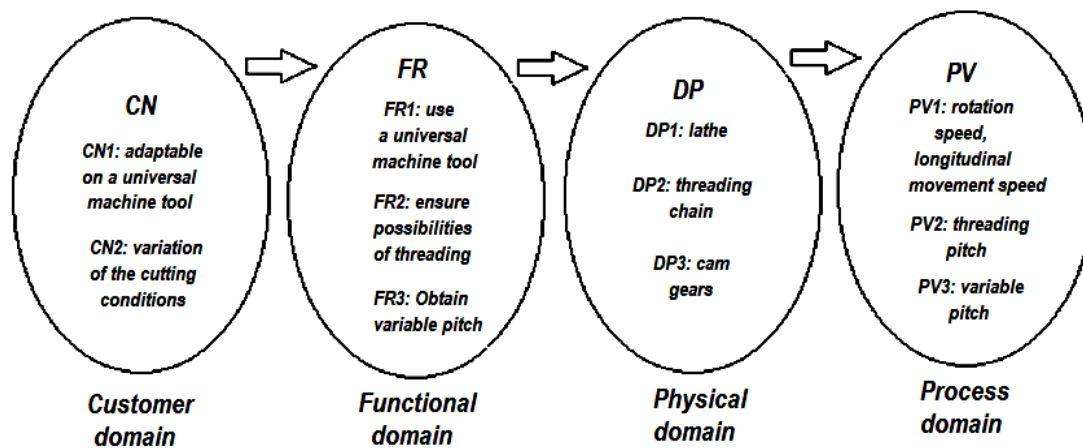


Figure 2. Domains specific to using the axiomatic design method in the case of a technological solution for variable pitch threading.

When applying the axiomatic design, the analysis of the main functional requirement (functional requirements of zero level, FR0) is continued by identifying the functional requirements of first level, of second level etc.

In the case of the desired technological solution, as functional requirements of first level, the following aspects could be taken into consideration:

FR1: Use a universal machine tool among the available machine-tools found in research laboratory;

FR2: Ensure possibilities of threading;

FR3: Ensure possibilities of machining threaded surfaces with variable pitches;

If the problem of identifying functional requirements of second order is formulated, one can take into consideration:

FR1.1: Use a rotation movement of workpiece;

FR1.2: Use distinct values for the rotation speed of the workpiece / test sample, in accordance with the type of workpiece material;

FR2.1: combine the workpiece rotation movement with a translation movement of the threading tool, characterized by a variable speed;

FR2.2: ensure possibility to change the speed of the longitudinal rectilinear movement of the cutting tool;

FR2.3: use a tool able to generate the thread profile;

FR3.1: ensure changing of the leading screw rotation speed just during the threading process;

FR3.2: ensure obtaining a certain variation of the lead screw rotation speed;

In the subsequently stage of applying the axiomatic design, *the design parameters* must be identified and eventually highlighted by means of a matrix. In the case of the approached problem, some of the considered design parameters could be:

DP1.1: main shaft of the lathe;

DP1.2: speed gear box of the lathe;

DP2.1: threading chain of the lathe;

DP2.2: gear train and feed gear box

DP2.3: threading tool

DP3.1: pair of cam-gears in the train gear;

DP3.2: profile of the cam gears.

The functional requirements and design parameters corresponding to the desired technological solution were included in table 2; one must mention that some simplifying assumptions were taken into consideration, in order to ensure only an illustration of the way in which the functional requirements could be formulated when the axiomatic design method is used.

By considering also other subsequently stages of applying the axiomatic design method, the solution schematically presented in Figure 4 was found as meeting the mentioned functional requirements. One can see that a pair of cam gears could be placed in the kinematic chain of the lathe, in order to change the rotation speed of the lathe lead screw and, in this way, to obtain a threaded surface with variable pitch. From the point of view of axiomatic design principles, the solution presented in Figure 4 could be affected by an improvement, since there are two functional requirements (FR3.1 and FR3.2) which are met by the same design parameter (DP3.1); this is the so called case of *coupled design*.

Table 2. Functional requirements and design parameters corresponding to use of axiomatic design method in the case of a technological solution for obtaining threaded surfaces with variable pitch.

Line no. 1	Design parameters					Design parameters						
2						Design parameters of first order						
3						DP1	DP2			DP3		
4						Design parameters of second order						
5	Functional requirements					DP1.1	DP1.2	DP2.1	DP2.2	DP2.3	DP3.1	DP3.2
6	2	3	4	5	6	7	8	9	10	11	12	
Col. no. 1												
7				FR1.1	X							
8		FR1	Func-	FR1.2		X						
9	Func-		tional				X					
10	requi-	FR2	requi-	FR2.1								
11	rements		ments	FR2.2				X				
12	of first		of second	FR2.3					X			
13	level	FR3	level	FR3.1						X		
				FR3.2						X	X	

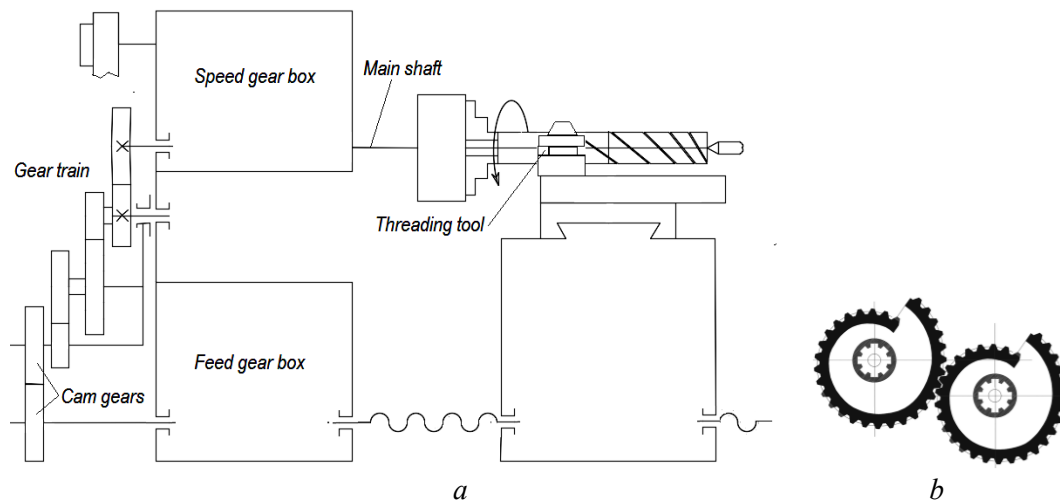


Figure 3. Schematic representation of the solution proposed for obtaining threaded surfaces with variable pitch (a) and cam gears which can be used in order to reach this objective (b).

Establishing the functions in the case of patent application

Another example of formulation the functions specific to designing an equipment for studying the machinability by drilling under constant force feed could be discussed in connection with the elaboration of a patent application. It is known that the so called *claims* could highlight the innovative solutions by considering functions able to ensure novelty, industrial application and inventiveness to the proposed technical solution. In fact, within a patent application, adequate answers to new or improved functions could be elaborated.

Table 3. Formulation of the functions leading to an improved solution for the equipment of testing the machinability by drilling under constant force feed.

Function code	Function name	Function category if the importance is considered	Solution (subassembly) proposed
A	Eliminating the stage of diminishing the error of coaxiality between the drill axis and the rotation axis of the test piece	Objective	Vice attached to the slide
B	Diminishing the possible influence of the friction forces in the guides of the slide supporting the test piece	Objective	Roller guide
C	Diminishing and balancing the force exerted by the slide and other parts during the drilling test	Objective	Balancing weight acting by means of pulley

An example concerning this aspect is presented in table 3 and the result could be seen in Figure 4.

Essentially, in the case of the test of drilling under constant force feed, the feed of drill into the test piece is materialized by means of a weight 1 of known value; by measuring the depth of the hole achieved in a certain testing time in the test piece material, one could obtain information concerning the machinability by drilling under constant force feed of the analyzed material. As a result of documentation activity [2, 3] and some experimental researches, one noticed that a high duration is necessary to ensure a certain coincidence between the axis of test sample found in rotation movement and the axis of drilling tool found in vice. In order to diminish the duration of this sequence (considered as a necessary function), one used a feed movement of the test sample (clamped in a vice), from up to down, to the drilling tool rotated by a motor placed on the machine tool table. In order to diminish the possibility of influencing the test results by the friction forces developed between the guide and the slide able to achieve the feed movement (this being an additional function – request), rollers guide were proposed to be used. Finally, a possibility to balance the weight of the slide should be found, in order to ensure a certain drilling force (this being the function to be met) and a pulley and a supplementary weight 2 were included in the test equipment.

The functions specific to the desired equipment (only those able to improve the known solution) are mentioned in the table 3.

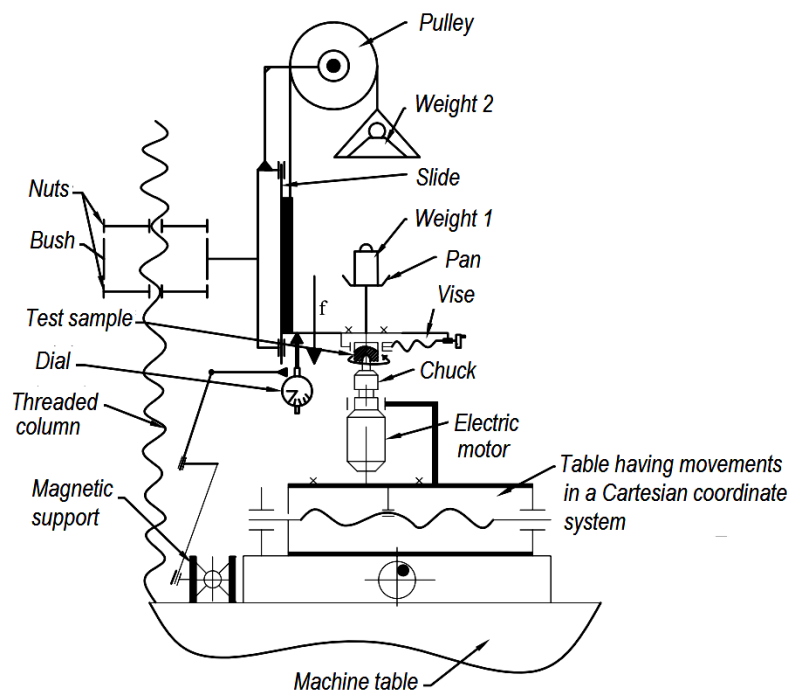


Figure 4. Schematic representation of the improved equipment for evaluation of the machinability by drilling under constant force feed.

4. Discussion and conclusions

Both in the case of applying the value analysis method and the axiomatic design method, the problem of defining the functions or requirements that must be met by the final technical solution is taken into consideration. Each of the above mentioned methods has proper rules and principles of defining *the product functions* – in the case of value analysis method and *the functional requirements*, in the case of axiomatic design method, respectively. There are distinct classifications and characteristics of the

functions that must be met by the final technical solution in the case of each of the discussed methods, but there are also common aspects.

In the present paper, the principles valid for the value analysis method were applied in the case of a water waste faucet and, respectively, the principles valid for the axiomatic design method were applied in order to identify and design a technological solution for obtaining threaded surfaces with variable pitch and adaptable on a universal machine tool. One can notice that the both methods are very useful in a clearer defining of the functions or of the requirements specific to the product to be designed and this is the main benefit of the applying the above mentioned methods. A second benefit could derive from the possibility of identifying new or improved solutions for the addressed problem and this fact was appreciated as corresponding to the proposed solutions for the desired products.

Another way of functions formulation is taken into consideration in the case of patent application elaboration, when the researcher must focus his preoccupations only on the functions able to add improvements or new advantages. An application of this aspect was considered for a device for evaluation of the materials machinability under constant force feed.

In the future, there is the intention to deeply study the other substages of applying the three methods, in order to improve the possibilities of their applying in the processes of products and processes design.

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