

ANALYSIS OF A DEVICE FOR WEDM BY MEANS OF PRICIPLES SPECIFIC TO AXIOMATIC DESIGN

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ABSTRACT: The research problem was the design of a device for wire electrical discharge machining adapted on a ram electrical discharge machine. A solution able to fulfil the initial requirements was identified. In order to improve the initial solution, the principles valid in the case of axiomatic design were applied. In this way, some aspects of design interest were found and discussed.
KEYWORDS: wire electrical discharge machining, machining device, axiomatic design, functional requirements, design matrix

1. INTRODUCTION TO AXIOMATIC DESIGN METHOD

In order to create a product that meets certain features, the customer (the one who develop the request) issues a requirement for a product that can have multiple subsections. In terms of hierarchy, this requirement is considered the highest or of zero level. From this level, the requirement is decomposed in descending order on to conception levels from the highest to lowest. If the product has only one requirement, then the hierarchy will be very simple, without needing the decomposition of each subsection, this leading quickly to a viable solution. If the requirement has several subsections, then the conception level will be decomposed, to reach further details that will shape the final product. In order to minimize unpleasant events created by the operator or by external factors, the product must be robust an easy to do. It can be said that the ensuring robustness and quality of a product should be achieved since the conception phase [3].

The above mentioned considerations are valid in the case of the axiomatic design method. This method has been initiated and developed by the Korean professor Suh Nam Pyo in papers published in 1978, when he worked at the Department of Mechanical Engineering at the Massachusetts Institute of Technology (U.S.A.) Subsequently, this method was discussed and applied by many researchers, at first for the development of production processes, while nowadays it has become an usual method for the design of various types of products, in the food processing industry, aerospace, automotive or architecture software. Axiomatic design method (AD) involves the use of two axioms that must simultaneously be followed. If one of them is not met during the design process, then the decomposition process will resume, not being allowed to continue, because this will create serious shortcomings in the final stages [6]. The axioms are:

A - independence axiom;

B – information axiom.

The first axiom refers to creating and maintaining the functional requirements (FR) at independent level one from the other, without any interconnection between them. In order to simplify the design act of a product, it is needed a minimum set of independent functions, which must characterize and fulfil the functioning conditions.

The second axiom establishes that the best solution that meets the axiom of independence is the one that requires minimal information and at the same time ensures the highest success probability. The measuring unit for information is the bit, for this being used logarithmic functions, if there are more requirements that must be fulfilled simultaneously.

2. PROCEDURE TO MANAGE AXIOMATIC DESIGN

The design of a product may be regarded as being part of four domain of requirements which derived from one into the other. These domains are the following:

1. *Customer domain,* in other words "what" is required by the consumer, or customer needs, CN;

2. Functional domain, this meaning the domain of product characteristics, namely the functions fulfilled by product, or functional requirements, FR. It is recommended that this requirement to be expressed through verbs and to have an imperative character.

3. Design parameters domain, in other words "how" to get the product, this meaning design parameters, DP. These parameters are established in

correspondence with the functions fulfilled by the product.

4. Process variables domain, in other words the product boundaries (process variables, PV) (see figure 1).

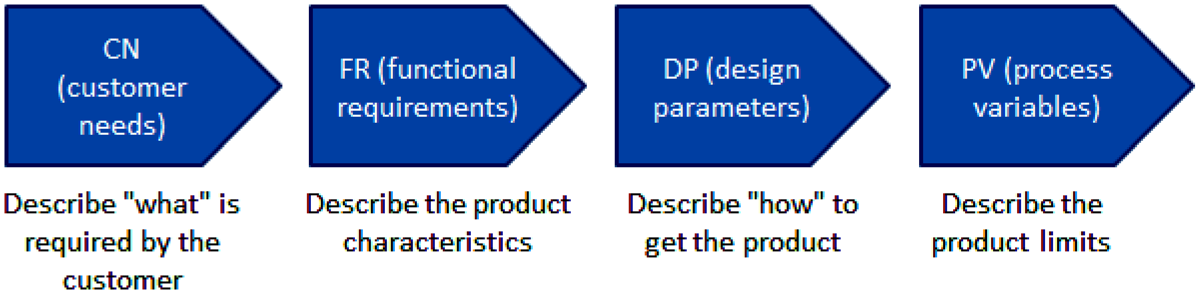

Figure 1. The four domains of axiomatic design

These domains are very important for fulfilling functions of the final product in the act of AD analyses, the domain from the right relative to the domain from the left, representing "what" and the left domain relative to the right domain represents "how" is done what is demanded in the left.

If say there is one function to be fulfilled, it is relatively easy to find the design parameters, but if there are multiple functions which should be taken into account, then the design becomes more challenging, because there is a high risk to violate the independence axiom. By mathematical formulations of this point of view, it can transpose by some formulas the interdependence between the functional requirements FR to be met and the design parameters DP [4]:

$$FR = [A]\,DP \qquad (1)$$

Formula number [1] shows the interdependence between functions to be fulfilled FR and design parameters DP. The term [A] is called the product conception matrix and it characterizes the product conception. According to the above shown formula, each function that is accomplished by the product can be written as [4]:

$$FR_i = \sum_{j=1}^{n} A_{ij} DP_j \,, \qquad (2)$$

where "n" represents the number of design parameters and "Aij" represents the matrix conception elements.

The elements of design matrix can be found by means of derivatives, using the following mathematical expression [4]:

$$A_{ij} = \frac{\partial FR_i}{\partial DP_j} \qquad (3)$$

In development of the design matrix, some terms may be zero, and there are two cases:

I. The first case which is desirable is the diagonal design matrix, and that is when Aij = 0 in all cases in which "i" is different from "j", as shown in the relation (4):

$$A = \begin{pmatrix} A_{11} & 0 & - & 0 \\ 0 & A_{22} & - & 0 \\ - & - & - & 0 \\ 0 & 0 & - & A_{nn} \end{pmatrix} \qquad (4)$$

II. The second case, which is although not desirable and it is achieved with a greater frequency, is the triangular matrix. This matrix type may be in the upper or it can be triangular at the lower part of the matrix, as shown in relation (5) [4].

$$A = \begin{pmatrix} A_{11} & 0 & - & 0 \\ A_{21} & A_{22} & - & 0 \\ - & - & - & 0 \\ A_{n1} & A_{n2} & - & A_{nn} \end{pmatrix} \qquad (5)$$

In this stage, it has been done the mathematical expression of the product fulfilled functions in relation to the design parameters. The next step is the introduction of design parameters in the manufacturing process variables. This can be mathematically written as follows:

$$DP = [B]\,PV \qquad (6)$$

In this case, [B] matrix is called the design matrix of the manufacturing process. As can be seen, this mathematical expression is similar to the product design matrix [A]. But this analysis is not always required.

In order to meet the independence axiom, three cases have been identified:

1. When the number of functions to be met is greater than the number of design parameters, it is called ***coupled design***.

2. When the number of functions to be fulfilled is less than the number of design parameters, this case is called as ***redundant design***.

3. When the number of functions to be met is equal to the number of design parameters, the situation corresponds to ***the ideal design***.

All three cases are valid only if the second axiom is fulfilled. But this can happen only if the conception matrix is diagonal (at best), these being called the ***uncoupled design***, or if the conception matrix is triangular (upper or lower) and these form will correspond to the ***decoupled design***.

The next step refers to the decomposition levels. It can be made by a zigzag scanning between the functions that must be fulfilled (FR) and the design parameters (DP). To verify if zigzag scanning decisions were taken properly, it is useful to write the design matrix equation, requiring that it must be diagonal or triangular. In order that the success probability is maximal and the resulted product is robust, it is ideally to satisfy the required functions with zero information. In this way, the product is tolerant to all design variations parameters as well as the process variables. If the matrix does not meet the needs of design objective, then the appropriate modifications will be made, by further continuing the analysis and modifying the factors from domains FR and DP. If at the end of the analysis, a convenient form of matrix design is reached, then it is needed to establish process variables (PV) using zigzag thinking method between DP and PV as it has done for previous domains. At the end, if axiomatic design rules are respected, it will lead to an optimal solution. In the next step, the product will be manufactured on a small scale and then tested accordingly. This method is increasingly wide used by designers, because it reduces the design time and in combination with other design methods such as, for example ideas diagram method and it can obtain the best solution in the shortest time.

3. APPLYING AXIOMATIC DESIGN PRINCIPLES FOR DEVELOPING A WEDM DEVICE

Further, axiomatic design method will be used for analyzing a wire electrical discharge machining (WEDM) device that will be fitted on a ram electrical discharge machine. It must be mentioned that the device was previously designed without taking into account the principles specific to axiomatic design method.

Customer requirements (CN) are as following:

CN1 - the device must be able to achieve WEDM machining;

CN2 - the device must be fitted on any ram EDM machine and in the same time should use all commended axes motions.

Primary functional requirements (FR), first level, or zero order, may look like this:

FR0 - design a wire electrical discharge machining device (WEDM), adaptable on a ram electrical discharge machine.

According to primary requirement (of zero order), this can be divided into several levels of order one.

FR1 - use the ram EDM machine available in the laboratory;

FR2 - provide electric wire winding of the coil;

FR3 - cut different sizes and shapes of parts at variables angles, but all this being in certain imposed limits by the ram EDM machine.

Functional requirements of the second level could have the following form:

FR1.1 – be able to use all rotational and translational motions of the ram EDM machine from the laboratory;

FR1.2 - have a device weight supported by the machine holder;

FR1.3 – ensure that the device dimensions are adjustable depending on the workpiece size;

FR1.4 - ensure the use of this device on any ram EDM machine similar to the one used in the laboratory, without requiring further modifications;

FR2.1 - achieve wire winding without endangering the axis linearity;

FR2.2 - stabilize the wire, in order to minimize the risk of breaking the wire;

FR2.3 - achieve the wire wrapping at variable speeds;

FR3.1 - use machining conditions given by the ram EDM machine, in order to ensure device simplicity and ease to use;

FR3.2 - provide a manual adjustment of the cutting angle in case that ram EDM machine cannot perform an adequate positioning.

The design parameters for the first level could be:

DP1 – Sodik AD3L;

DP2 - wrapping and unwrapping the spool;

DP3 - rapporteur and small conical wire guides to fit in small workpieces holes;

Design parameters (DP) for the second level can have the following form:

DP1.1 - small and simple design, easy to adjust and maintain, Sodick AD3L;

DP1.2 - materials used for the supportive components will be steel and for guiding will be PLA. All components will have internal holes or channels, in order to reduce the device weight.

DP1.3 - the possibility to slide the guides through approaching or distancing them along the main axis of the device;

DP1.4 - the part designed for mounting the device to the ram EDM machine holder is small in size, having a simple geometric shape and being easy to use;

DP2.1 - achieving a minimum diameter of the winding-unwinding wire drum;
DP2.2 - adding screws, washer nozzles and nuts for adjusting thread tension;
DP2.3 - installing an electronic speed variator;
DP3.1 - removing the need of dielectric substance to be accurately guided to the electric wire, as it is used on specialized WEDM machines.
DP3.2 - manual adjustment with screws for the rapporteur and sliding guides.

In this case, the matrix of order 1 will have the following aspect:

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \end{Bmatrix} = \begin{pmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{pmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \end{Bmatrix} \quad (7)$$

The matrix forms of second level will have the following shapes:

$$\begin{Bmatrix} FR1.1 \\ FR1.2 \\ FR1.3 \\ FR1.4 \end{Bmatrix} = \begin{pmatrix} X & 0 & 0 & 0 \\ 0 & X & 0 & 0 \\ 0 & 0 & X & 0 \\ 0 & 0 & 0 & X \end{pmatrix} \begin{Bmatrix} DP1.1 \\ DP1.2 \\ DP1.3 \\ DP1.4 \end{Bmatrix} \quad (8)$$

$$\begin{Bmatrix} FR2.1 \\ FR2.2 \\ FR2.3 \end{Bmatrix} = \begin{pmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{pmatrix} \begin{Bmatrix} DP2.1 \\ DP2.2 \\ DP2.3 \end{Bmatrix} \quad (9)$$

$$\begin{Bmatrix} FR3.1 \\ FR3.2 \end{Bmatrix} = \begin{pmatrix} X & 0 \\ 0 & X \end{pmatrix} \begin{Bmatrix} DP3.1 \\ DP3.2 \end{Bmatrix} \quad (10)$$

			DP								
		Level 1	1				2			3	
	Level 1	Level 2	1	1	1	1	2	2	2	3	3
FR	1	1.1	X								
		1.2		X							
		1.3			X						
		1.4				X					
	2	2.1					X				
		2.2						X			
		2.3							X		
	3	3.1								X	
		3.2									X

Figure 2. Design matrix for WEDM device adaptable on a ram EDM machine.

From the above mathematical relations, it can be seen that the number of functional requirements (FR) coincides with the number of design parameters (DP). In this case, the matrix is diagonal, so it can be said that these models belong to ideal uncoupled conception. This shows that the first axiom was fulfilled. It can be seen also that there is a descending order of the member's number of the matrix from four to two.

As a process variable (PV), the followings may be considered;

1 - the machining possibility of parts within certain dimensional limits. These limits are given by the supported weight of the machining head of the ram EDM machine, because a larger WEDM device leads to more weight. The shape and size of the tank in which the WEDM device is submerged have also an important influence;

2 - short circuit between the wire electrode and the tool electrode. This parameter is limited by the flow speed of dielectric fluid in the space between the electrodes, because it is not directed by a nozzle along the axis of the wire, as it is used at specialized WEDM machines. Because of this, it may be interposed accumulation of electro conductive micro-granules which will cause short circuits, and also machining speed reduces. However it is possible to avoid short circuits by means of the correct functioning of electronic surveillance subassembly and also by watching and adjusting variation of specific machining parameters;

3 - the nature and the shape of the of workpiece material. It could be said that the material from which the workpiece is made could be a technology limitation, because there can be machined only the electrically conductive material. An advantage is the fact that the workpiece may have thin walls, because the part is not in contact with the tool. The machining shape introduce limitations in the use of the WEDM device only for general cutting or internal complex shape pierced machining. As a final result, the design matrix for a WEDM device suitable for ram EDM machine is presented in figure 3.

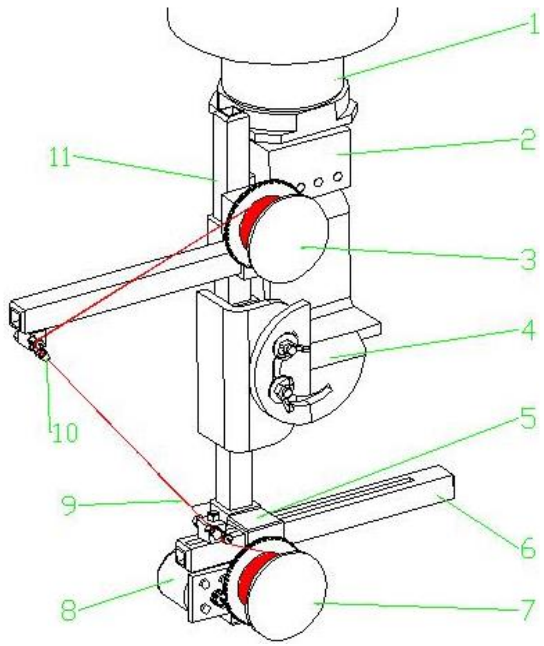

Figure 3. Constructive version of the device for machining with wire tool electrode adaptable on a ram EDM machine Sodick AD3L

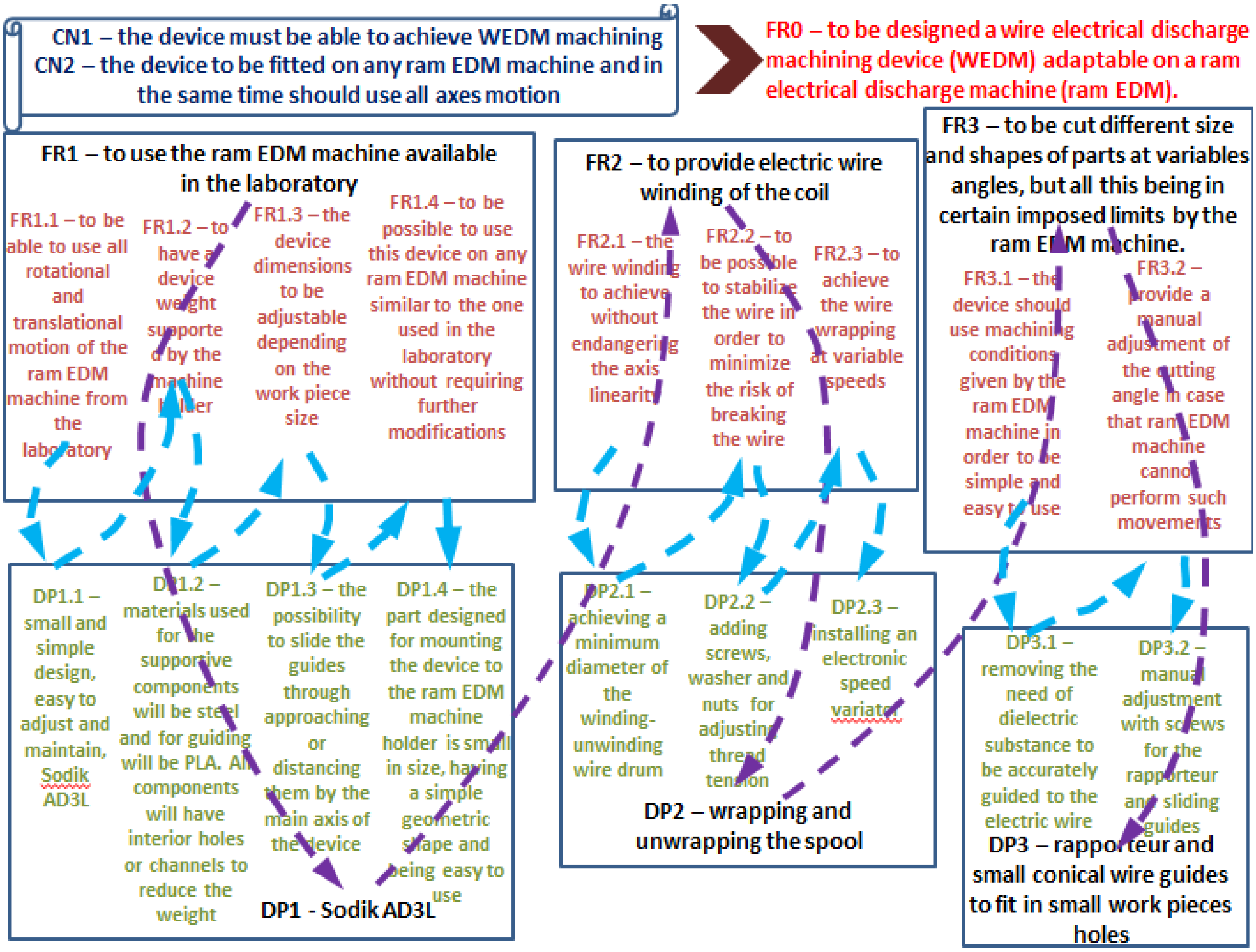

Figure 4. Ranking and correlation of functional requirements (FR) with design parameters (DP) by zigzag sweeping

In the design process of the device, there have been found several constructive variants. In order to meet the information axiom, there were removed some requirements, taking into account only those who have a minimum of information and have the highest probability of success, ultimately resulting in the functionality of designed components.

4. PROPOSED SOLUTION

Based on the above mentioned factors, constructive solution may take the form shown in figure 3. The main component of this device may be considered the spool for winding-unwinding the electric wire. Starting with this element, there have been developed the subsystems and the components to support and guide the electric wire. Thus, there are two coils (3 and 7) each one for supporting the ends of the wire. The winding-unwinding movement of the wire is provided by an electric motor (8), using a gear train reducer. Revolutions per minute range are manually controlled via a potentiometer. In order to reduce the weight, the coils are supported by a shaft, using two bearings on a special designed support (5). This can slide on the main axis of the device (11). Through inside hole of this support, another guide (6) is used, for this the main function being to support electric wire guides (10). Further the component that represents also the main axis of the device is sustained by a rapporteur (4) for manually setting up the machining angle. This component is integrated with the part (2), which supports the entire device on the machining head of the ram EDM machine which is Sodick AD3L (1), located in the accessible laboratory. In order to have a weight as low as possible, some components may be made of plastic material, such as the material of the coil support, the guides for frames coils support (6), the electrical wire guides support (10) and the support for fixing the electric motor.

5. CONCLUSIONS

Axiomatic design method allowed the analysis of design aspects that were initially neglected when designing the initial version of the device. There have been identified the product characteristics (FR), how to obtain these product characteristics (DP) as well as the boundaries that this device can have (PV). By zigzag scanning, it has been reached in an operative manner at a simple as possible constructive solutions. By using findings related to the applying of the axiomatic design method, in the future, there is the intention to design this device with the possibility of automatic winding in a reverse movement direction of the wire electrode, by positioning an electric motor on the other coil, where nowadays there was not included. Conception, design and materializing a WEDM device adaptable on a ram EDM machine is necessary because it would bring important cost savings. Cost savings is justified because one has a ram EDM machine, there is no need to buy a WEDM machine, which is very expensive, instead using a WEDM device adaptable on any ram EDM machine which is much cheaper and easy to maintain.

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