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APPLYING PRINCIPLES OF AXIOMATIC DESIGN IN THE CASE OF A DEVICE FOR ROTATIONAL MOLDING

Laurenţiu SLĂTINEANU[1], Oana DODUN[2], Margareta COTEAŢĂ[3,*], Maricela POIENARU[4], Alina OANCEA[4], Irina BEŞLIU[5]

1) Prof., PhD, Department of Machine Manufacturing Technology, "Gheorghe Asachi" Technical University of Iaşi, Romania
2) Assoc. prof., PhD, Department of Machine Manufacturing Technology, "Gheorghe Asachi" Technical University of Iaşi, Romania
3) Lecturer, PhD, Department of Machine Manufacturing Technology, "Gheorghe Asachi" Technical University of Iaşi, Romania
4) Master student, Department of Machine Manufacturing Technology, "Gheorghe Asachi" Technical University of Iaşi, Romania
5) Junior Assistant, Department of Mechanics and Technologies, University "Ştefan cel Mare" of Suceava, Romania

Abstract: *Axiomatic design is a design method promoted and applied in the last decades in order to help the designer in systemizing his activity, by taking into consideration some essential principles proposed by the Korean scientist Num Suh Pyo et the end of the previous century . On the other hand, the rotational molding is a manufacturing method applied when hollow parts made of plastic are necessary. The method is based on the rotation of the mold around two perpendicular axes. The paper presents the results obtained by taking into consideration the principles of axiomatic design in the case of a device adaptable on a universal lathe. The device is able to facilitate the application and the study of the rotational molding of plastic parts. The placement of the device on a lathe should ensure a simple modification of the rotational speed. Chain and conical gear transmissions were used to obtain the second rotational motion. The analysis developed by means of the stages specific to the axiomatic design facilitated the highlighting of some specific functional requirements and practical solutions for defining the design parameters. A matrix model was conceived by taking into consideration the functional requirements and the design parameters. There were defined three groups of functional requirements; uncoupled and uncoupled solutions were identified. As direct result of applying the principles specific to the axiomatic design, a constructive solution for a device allowing the applying of the rotational molding was proposed.*

Key words: *axiomatic design, principles, rotational molding, plastic part, device, lathe, motion transmission.*

1. INTRODUCTION

Nowadays, one of the scientific research significant objectives is the integrated approaching of the product life; new knowledge are established and applied by taking into consideration the whole existence of the product, from the identifying of a market need and to the stage when the product is disassembled and its parts are analyzed in order to determine the possible reuse or sending to the enterprises where the workpieces are obtained in various ways.

Within the life cycle of a certain product, after the stage of selecting and sketching a possible solution, *a design stage* is necessary; this activity must be finalized by approving and delivering the drawings necessary in the manufacturing process.

In order to optimize the design process, various methods could be used: design for six sigma [11], TRIZ (theory of inventive problem solving) [13], method of systematic design, the global design method entitled "new product design" etc.

One of the methods used in the last decades is the so-called method of axiomatic design [14]. The first researches in the field of axiomatic design were developed by the Korean scientist Nam Suh Pyo, when he was professor at the Massachusetts Institute of Technology from Boston (United States of America); one must specify that the Korean professor considered that a new structure of the mechanical engineering is necessary, by passing from the knowledge based exclusively on physical phenomena to knowledge which takes also into consideration knowledge belonging to biology and informatics. He expressed also the opinion that the knowledge about design and manufacturing processes must be assimilated just within the high school education. One may consider that there are three essential principles including the so-called axioms, domains and zigzag processes.

The domain of the axiomatic design are: 1*)* The customer domain, where the customer needs (*CNs*) are highlighted; 2) Functional field, where the functional requirements (*FRs*) are specified; 3) Physical domain, where there are Design Parameters (*DPs*); 4) Process field, concerning the Process Variables (*PVs*).

In accordance with the principles of the axiomatic design, two axioms could be considered:

* Corresponding author: Department of Machine Manufacturing Technology, "Gheorghe Asachi" Technical University, Iaşi – 700050, Romania
Tel.: +40 232 278689/2313;
Fax: +40 232 217290;
E-mail addresses: *slati@tcm.tuiasi.ro* (L. Slătineanu), *oanad@tcm.tuiasi.ro* (O. Dodun), *mcoteata@yahoo.com* (M. Coteaţă), *grigorasirina_sv@yahoo.com* (I. Beşliu).

A1. The axiom of independency; in accordance with this axiom, the functions of a device (Functional Requirements) must be considered as independent;

A2. The axiom of information; this axiom needs that the quantity of information necessary in order to develop the activities of the product design must be minimum.

There are various ways to apply the principles of axiomatic design in the social-economic activities; there were developed investigations concerning the applying of the axiomatic design in manufacturing engineering, in design of highways, study of impact phenomena, planning the surgery activities, improving of the pharmaceutical products quality when such activities have not an urgent character, water waste etc. In order to change information concerning the axiomatic design, the results of research activities and applications, at each two years, an international conference is organized [6 and 7].

The specialty literature highlight a diversity of applications and research subjects concerning the axiomatic design and connections of this method with other design methods.

Thus, Nathalie Lahonde developed a doctoral research concerning the optimization of de design process (by taking into consideration inclusively the axiomatic design) and proposed a model applicable in selection of the methods able to help the decisions making [8].

Houshmand and Mokhtar [7] analyzed the possibilities to use a road-map in order to implement universal manufacturing platform considering the axiomatic design methodology. They appreciated that a significant challenge could be the development of investigations concerning the new controllers for a large set of devices and equipments so as robots, conveyors etc.

Han et al. [6] used the axiomatic design in order to define a high-brightness wafer dicing machine, so that the mechanical and thermal effects are minimized. As process equipment, they used an ultra-fast based non-thermal LED dicing machine. The design parameters were established as result of a detailed investigation of the interaction between the laser pulses and the workpiece material.

Grozav [5] explained (2008) the significance of the axiomatic design for the improving of the product quality; he considered that the design must take into consideration the quality requirements imposed by the customer. He highlighted also the usefulness of making hierarchies and zigzag decompositions for identifying the optimal solutions of the product.

A parallel could be made between two ways applicable in finding the product functions [2]; thus, within the axiomatic design, the functions are identified as result of a zigzagging and hierarchical technique, while in the systematic design successive additions facilitate the function decomposition.

Gonçalves-Coelho and Mourão [4] took into consideration the axiomatic design as a tool for better analysis of each product and related manufacturing processes; they highlighted also the possibility to use the axiomatic design as a support for the decision – making process in the design of manufacturing processes.

2. PROBLEM FORMULATION

In the Department of Machine Manufacturing Technology from the “Gheorghe Asachi” Technical University of Iaşi, there was the intention to develop a research concerning the so-called rotational molding method of obtaining plastic parts (Fig. 1).

It is known that the rotational molding is a manufacturing process which allows the obtaining of parts with hollow forms and having an approximately constant thickness of the part walls.

Essentially, the rotational molding supposes the rotation of the mold so that the liquid material found in the mold cavity flows, contacts the internal walls of the cavity and solidifies on these walls (Fig. 1). Finally, the external shape of the part corresponds to the cavity internal

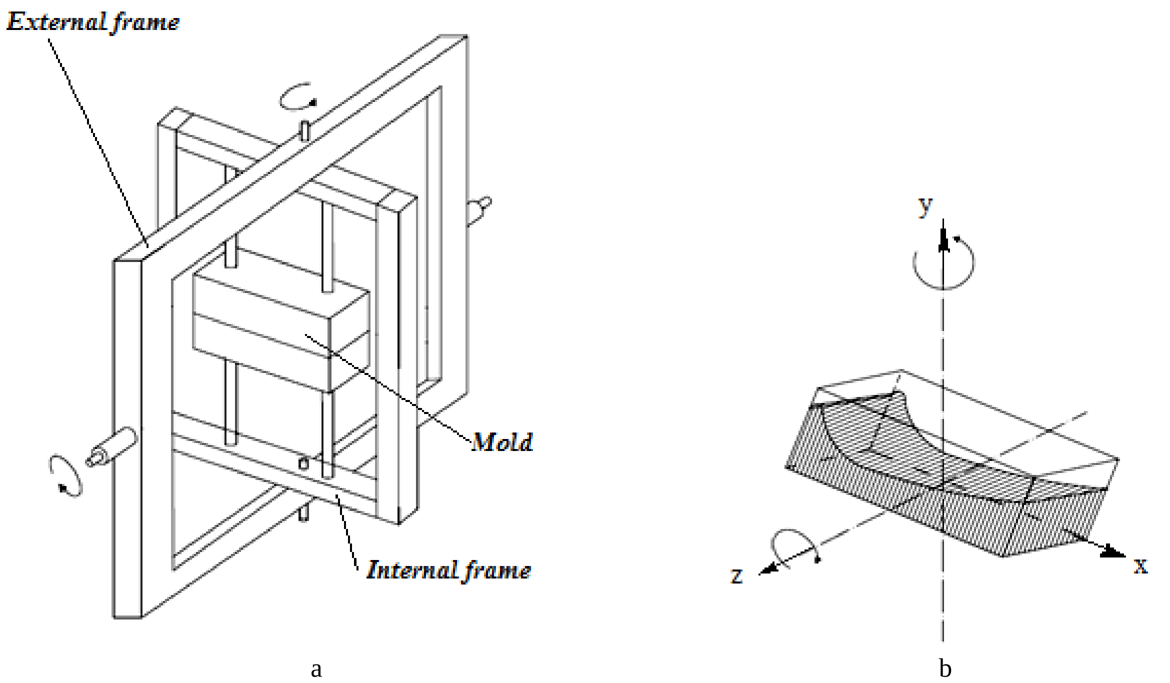

Fig. 1. Schematical representation of the rotational molding process: *a* – mold rotation around two perpendicular axes; *b* – contact of the plastic liquid with the mold walls, as a consequence of the two rotation motions.

shape. In industrial companies, there is the possibility to heat the mold, so that the material introduced as a powder into the mold is affected by a melting process; afterwards, as consequence of the mold rotation around two perpendicular axes, the liquid plastic material adheres to the mold cavity walls. When the liquid material adhered sufficiently to the cavity walls, a cooling process may be started, while the mold rotates yet. After to solidification of the material found into the mold, the rotation motions stops and by opening the mold, the part could be extracted.

In the case of simplified equipment of rotational molding, two components are used in order to obtain a plastic part; a component is a liquid material and the second component may be the substance which could be added to the first liquid and which determines the solidifying of the this liquid material.

As one can see, the results of applying the rotational molding process could be influenced by many groups of factors: properties of the plastic material, its capacity to adhere to the cavity walls and to solidify in a reasonable time interval etc.), and some kinetic conditions.

Thus, the rotation of the mold must be so materialized that the liquid material contacts entirely the cavity walls, but without developing high centrifugal forces, able to generate the accumulation of the liquid material in certain pits of the cavity. The rotation motions around two perpendicular axes must be characterized by speeds which allow the contact between the liquid material and the mold cavity; as above mentioned, at the same time, the rotation speed must be not too high, to not generate significant centrifugal forces (4 – 40 rpm).

In accordance with such conditions, usually experimental researches are necessary to determine the optimal kinetic parameters specific to the rotational molding process; such researches were developed in various research laboratories.

Gogos et al. [3] proposed initially a detailed theoretical model specific to the rotational molding process of plastics; afterwards, differential and lumped parameter numerical models were developed. The authors mentioned that the results of applying the proposed models are in a good agreement with the experimental data identified in the specialty literature and allow the study of influence exerted by some key dimensionless groups on the process duration.

A finite element simulation model concerning the thermal phenomena developed during the rotational molding of plastics was proposed by Olson et al. [10]; they made also several experimental tests, in order to establish the correspondence of the simulation model with the real situations. The considered that the discrepancy between the results obtained by using the model and the experimental results could be explained by the treatment of the phase change in the simulation; they expressed the intention to extend the researches about the detailed temperature profiles specific to the process.

Various actual applications of the rotational molding were highlighted by Mapleston [9]. He considered that some developments were possible on the base of creating marked improvements. A significant advantage of the rotational molding is the simplicity of the equipment; as disadvantages, one may mention the low productivity and the possible variation of the products quality.

Abu-Al-Nadi et al. [1] used adaptive fuzzy systems in order to control the rotational molding process, especially the machine oven temperature, by considering the some process parameters. They concluded that the adaptive fuzzy network could be applied in manipulated opening of the valve on the fuel system.

Revyako and Khrol developed [12] a research concerning the heat and mass transfer during the rotational molding process. They elaborated a theoretical model which could be applied in order to optimize the process parameters and to find the optimum design of the molding tool for practical applications.

In this way, the necessity to design and achieve equipment or a device able to allow some researches concerning the rotational molding appeared.

3. APPLYING OF SOME PRINCIPLES SPECIFIC TO THE AXIOMATIC DESIGN

In order to apply some elements specific to the axiomatic design in such a case (Fig. 2), some customer needs could be formulated; as a customer, one can consider a researcher interested to better understand and to study the process of rotational molding.

Thus, the customer needs could be the following:

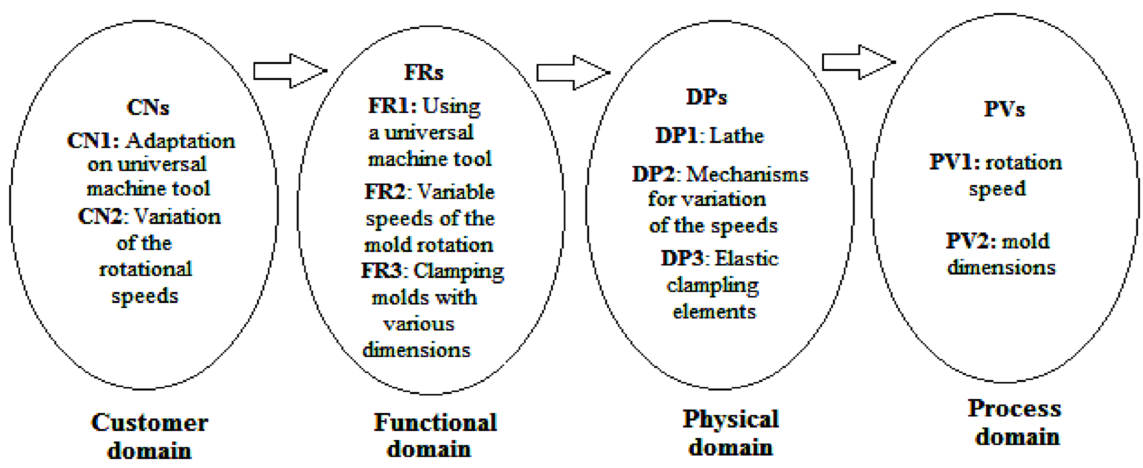

Fig. 2. Domains specific to the axiomatic design of the device for the study of the rotational molding.

1. The equipment could be adapted on a universal cutting machine tool, by taking into consideration the fact that such machine tools offer a relatively large set of rotation speeds of their main shaft;

2. In order to be used for reaching some research objectives, the device could ensure a possibility to change the rotational speeds of the mold.

Because in the laboratory for non-conventional technologies there was a lathe, the decision to use this machine-tool was established. The main functional requirement could be the following:

FR0: Clamping the mold and ensuring two variable rotation motions around two perpendicular axes.

The deeper analysis may highlight (Table 1) *the functional requirements (FRs) of first level:*

FR1: Using a universal machine tool from the laboratory of non-conventional technologies, in order to obtain variable rotational speeds at least for the entering shaft of the device;

FR2: Ensuring variable speeds of the mold rotation around the second rotation axis;

FR3: Ensuring the clamping of the mold having various dimensions.

The second-level requirements could be the following:

FR1.1. Obtaining the rotational motion from the main shaft of the machine tool;

FR1.2. Ensuring a variable rotation speeds of the mold around the horizontal axes;

FR1.3. Transmission of the motion in order to obtain the rotational motion of the mold around a horizontal motion;

FR1.4. Compensation of the eventual deviation from the alignment;

FR1.5. Possibility to adapt the device on various machine tools of the same type;

FR2.1. Obtaining the second rotational motion from the main rotational motion;

FR2.2. Transmission of the second rotational motion to the subassembly in which the mold is clamped;

FR2.3. Changing the direction of the second rotational motion;

FR2.4. Ensuring variable rotation speeds of the mold around a vertical axis;

FR3.1. Accepting molds with various dimensions;

FR3.2. Positioning the mold;

FR3.3. Fixing the mold in the device.

One can take into consideration *the design parameters DPs* corresponding to the first level functional requirement FRs:

DP1.1. Lathe;

DP1.2. Gearbox of the lathe;

DP1.3. Transmission of the motion by shafts;

DP1.4. Double Cardan shaft;

DP1.5. Possibility to place the transmission shaft at various heights;

DP2.1. Chain transmission with a fix wheel;

DP2.2. Chain transmission;

DP2.3. Conical gear transmission;

DP2.4. Chain transmission with changeable chain wheels;

DP3.1. Elastic elements of clamping;

DP3.2. Alternating dispositions of the elastic elements;

DP3.3. Elastic elements whose contractions clamp the mold.

Zigzagging activities were developed during the elaboration of the functional requirements and finding design parameters. In this way, there was find the requirement that the device have a possibility to be adaptable not on the first lathe identified in the laboratory of non-conventional technologies from the “Gheorghe Asachi” Technical University of Iaşi - Romania, but also on other type of lathe existing within the department; such a requirement could be considered in the development of a future device of rotational molding. As result of the activities of defining the functional requirements *FRs* and the solutions to adequately answer to these requirements, the Table 1 was elaborated. In this table, the functional requirements at various levels were inscribed

Table 1

Functional requirements and design parameters

Line no.1					**Design parameters DPS**											
2					**Design parameters of first level**											
3					**DP1**					**DP2**				**DP3**		
4					Design parameters of second level											
5					**DP1.1**	**DP1.2**	**DP1.3**	**DP1.4**	**DP1.5**	**DP2.1**	**DP2.2**	**DP2.3**	**DP2.4**	**DP3.1**	**DP3.2**	**DP3.3**
6 Col. no. 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	17	18
7	Functional requirements of first level	FR1	Functional requirements of second level	FR1.1	X											
8				FR1.2		X										
9				FR1.3			X									
10				FR1.4				X								
11				FR1.5					X							
12		FR2		FR2.1						X						
13				FR2.2							X					
14				FR2.3								X				
15				FR2.4									X			
16		FR3		FR3.1										X		
17				FR3.2.											X	
18				FR3.3												X

along the columns, while the design parameters were included along a horizontal line. The correspondence among the functional requirements and the design parameters able to materialize the functional requirements were highlighted by using the letter *X*.

The matrix expression corresponding to the information included in Table 1 about the first level of the functional requirements and design parameters is the following:

$$\begin{Bmatrix} FR1 \\ FR2 \\ FR3 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP1 \\ DP2 \\ DP3 \end{Bmatrix}. \qquad (1)$$

One may notice that in such a case there are uncoupled designs. Uncoupled designs could be find also in the case of the functional requirements and design parameters corresponding to the *first group of functional requirements:*

$$\begin{Bmatrix} FR1.1 \\ FR1.2 \\ FR1.3 \\ FR1.4 \\ FR1.5 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 & 0 \\ 0 & X & 0 & 0 & 0 \\ 0 & 0 & X & 0 & 0 \\ 0 & 0 & 0 & X & 0 \\ 0 & 0 & 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP1.1 \\ DP1.2 \\ DP1.3 \\ DP1.4. \\ DP1.5 \end{Bmatrix}. \qquad (2)$$

In the case *of the second group of functional requirements*, uncoupled design seems to be applied, but there are also solutions when design parameter could be used in order to materialize various functional requirements:

$$\begin{Bmatrix} FR2.1 \\ FR2.2 \\ FR2.3 \\ FR2.4 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 & 0 \\ 0 & X & 0 & 0 \\ 0 & 0 & X & 0 \\ 0 & 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP2.1 \\ DP2.2 \\ DP2.3 \\ DP2.4 \end{Bmatrix}. \qquad (3)$$

An uncoupled design may be found also in the case of the third group of functional requirements *FR3*:

$$\begin{Bmatrix} FR3.1 \\ FR3.2 \\ FR3.3 \end{Bmatrix} = \begin{bmatrix} X & 0 & 0 \\ 0 & X & 0 \\ 0 & 0 & X \end{bmatrix} \begin{Bmatrix} DP3.1 \\ DP3.2 \\ DP3.3 \end{Bmatrix}. \qquad (4)$$

As *process variables* (*PVs*), one can consider: 1) Rotation speeds of the mold around two perpendicular axis; 2) Possibilities to clamp molds with various dimensions.

4. PROPOSED SOLUTION

In accordance with the above mentioned considerations, the solution presented in Fig. 3 was proposed and developed. One can see that the device for the study of the rotational molding may be placed on the cross slide of a universal lathe.

The rotation motion could be obtained by means of the universal chuck mounted on the main shaft of the lathe; indeed, a cylindrical bar is fixed in the universal chuck. The rotational motion is transmitted to the shaft necessary to obtain the rotational motion of the mold around a horizontal axis by means of a double Cardan shaft. The presence of such a coupling ensures conditions to use the device on another universal lathe, characterized by some different dimensions in comparison with the device considered initially. The double Cardan shaft is necessary also to compensate eventual low differences concerning the deviation from the alignment between the main shaft of the lathe and the shaft for achieving the rotational motion of the mold around the horizontal axis.

A second solution necessary to compensate some differences between the positions of the lathe main shaft and the horizontal shaft of the device must ensure the motion of the horizontal axis on the vertical motion and fixing it in a position which corresponds approximately to the position of the lathe main shaft.

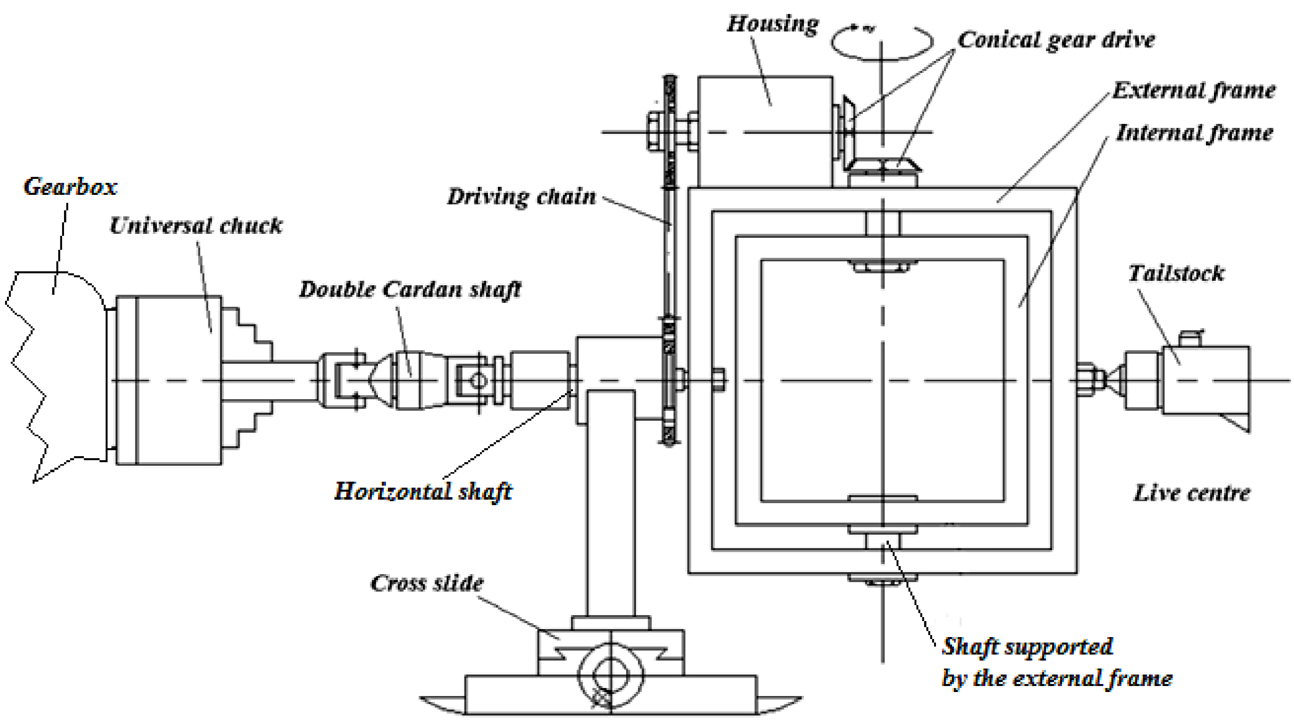

Fig. 3. Structure of the device for study of the rotational molding.

The horizontal shaft of the device is placed on two cylindrical ball bearings found in a metallic housing; a housing cover allows the adjusting of the space between the elements of the ball bearings. A fix chain wheel is clamped by screws on the housing cover. At the same time, an external frame made of wood is fixed by means of a nut on the right end of the horizontal shaft. On this external frame (which is rotated by the horizontal shaft around a horizontal axis), a wood housing was mounted to support the shaft which receives the rotational motion from the horizontal shaft of the device.

This shaft is placed on two ball bearings; at the left end of the shaft, there is a chain wheel trained in a rotational motion as a consequence of the external frame rotation. At the right end of the shaft, there is a first conical gear which transmits the rotational motion to a shaft on which the internal frame is placed; in this way, the second rotation motion (around an initial vertical axis – Fig. 3) of the mold may be ensured. In its opposite end, the internal frame has a shaft supported by the external frame.

In order to simplify the constructive solution, the external frame has a small metallic cylindrical bolt in which a center hole exists; in this way, the external frame is supplementary supported by the live centre.

As above mentioned, the mold could be clamped in the internal frame by means of some elastic ribbons.

5. CONCLUSIONS

The axiomatic design is a design method based essentially on applying the axiom of the functions independence and the axiom of using minimum information. This design method could be applied in order to solve various economical and industrial problems. On the other hand, the rotational molding is a manufacturing method supposing the rotation of the mold around two perpendicular axes. In order to design a device able to be used for developing investigations concerning the axiomatic design, some stages specific to the axiomatic design were applied; the use of the axiomatic design principles facilitated the identification of a solution corresponding to the assumed objectives Thus, a device adaptable on a universal lathe and which ensures the rotations of the mold around two perpendicular axes was designed. In the future, there is the intention to manufacture such a device and to experimentally study the rotational molding process, in order to determine the influence exerted by some input factors on the parameters which characterize the quality of the product.

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