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USE OF SOME TRIZ PRINCIPLES IN THE CASE OF DESIGNING RESEARCH EQUIPMENT

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Abstract: *If in the case of the routine design of equipment or manufacturing technology, there is not necessary to identify and apply improvements of equipment or manufacturing technology, when applying the creative design, improved solutions must be found at least for some of the designed objects. Different methods could be applied to identify the ways of improving the object of the design activities, and the theory of solving the creative problems is a useful tool that can be used to solve such problems. Some of the principles of the theory of solving creative problems were applied in the cases of identifying innovative solutions for the components of experimental equipment developed in doctoral research. Thus, the way of defining the main contradiction, of using elements from the operational zone or from the oversystem, and the informational fund in the cases of some equipment for manufacturing or of different process scientific investigation was approached. The use of TRIZ facilitated the identification of improved ways of solving the problems of doctoral research interest.*

Key words: *Input factors, Creative design, Experimental equipment, Theoretical research, End milling.*

1. INTRODUCTION

Design as problem-solving represents a natural thing and, at the same time, one of the most applied of human activities. The design process begins with the acceptance of the needs of a product or process and also the weakness of the cur-rent status. Hence, some actions have to take place in order to solve design problems [3].

Generally, the concept of *design* refers to the action of modeling, sketching a new product (object or system), or performing the technical-economic calculations of the output, which will result in a prototype, product, or process. In other words, it refers to the schematization on a board or using a commercial CAD software package such as CATIA, SolidWorks, Creo, Pro engineer, Inventor [17, 16], etc.

From the very beginning, it has been the duty of science disciplines to teach us about natural things: how they are and how they work. It has been the main purpose of the engineering domain to offer a better understating of artificial things like how to make products that meet the requested properties and how they are designed [10]. The functional design step of a development project targets the actions of a new or revised product, program, service, or process and also refers to a transition between the requirement analysis and the detailed design [18].

The concept of Design for Manufacture / Manufacturing (DFM) has a large spread among engineers. By DFM, we understand establishing the shape of components to allow for efficient, high-quality manufacture, according to Ullman (2010) [11].

Matsuoka made a classification of those design activities in 2008. He endorses that are three categories of design activities: "design thinking", "design method-ology", and "form of data". The design process involves going through "design problem analysis", which is derived from intuition, "idea generation", which comes from instinct and "idea evaluation", which is derived from the deduction [1].

TRIZ is a knowledge-based methodology for creative problem-solving. This method is mainly used to develop new technical solutions, providing a systematic approach for innovative findings [3]. Jani showed in 2013 that TRIZ methodology has a great spread among engineering schools. Because of its effectiveness in solving complex problems, the method was used even in the education system to develop the Innovation Education concept. The author of the paper concluded that TRIZ had become one of the most popular problem-solving methods [6].

In recent decades, the TRIZ method of solving invention problems, as its name suggests, has been widely applied in various fields to solve the inventive problem. At the base of the method, the 39 parameters of the contradiction matrix, respectively, the 40 principles of inventiveness [22] are placed. According to Chechurin & Borgianni, the usefulness of this method is still debatable [4]. Bang et al. conducted research that provided an overview of what constructive design research means. The authors mentioned, among other aspects, that design as a process could be considered as "a science of imagination" [9].

Going to another perspective, Borgianni & Matt mentioned in their scientific paper a comparison between TRIZ methodology (for solving circumstantiated contradictions) and Axiomatic Design (for problem analysis). The authors analyzed the findings of other researchers and suggested that both methods have limitations regarding the area of application, mainly in the case of complex systems. From their point of view, a combination of TRIZ capabilities and Axiomatic Design optimization advantages could satisfy more complex problems [5].

This paper aims to identify creative and innovative solutions by using a part of TRIZ principles for various research equipment, which will be used later in experimental research. To get the result of the scientific work, the fundamental bases of the method were taken into consideration. Thus, these are as follow: the 39 parameters of the contradiction matrix (size, area, volume, speed, pressure, shape, manufacturing precision, etc.), respectively the 40 principles of inventiveness (local quality, segmentation, universality, asymmetry, homogeneity, composite materials, etc.).

2. APPLYING SOME OF TRIZ PRINCIPLES TO DESIGN PROCESSES OR EQUIPMENT FOR IN DOCTORAL RESEARCH ACTIVITIES

The main purpose of this paper is to identify creative solutions in the case of research equipment in different fields. Hence, in order to get the final results, the TRIZ method was approached. The version of the method is ARIZ 85 V, which includes 9 main steps, 40 steps of successive analysis, and 70 rules and observations, respectively (mentioned in figure 1).

Thus, some principles of the method have been used to solve problems belonging essentially to industrial engineering.

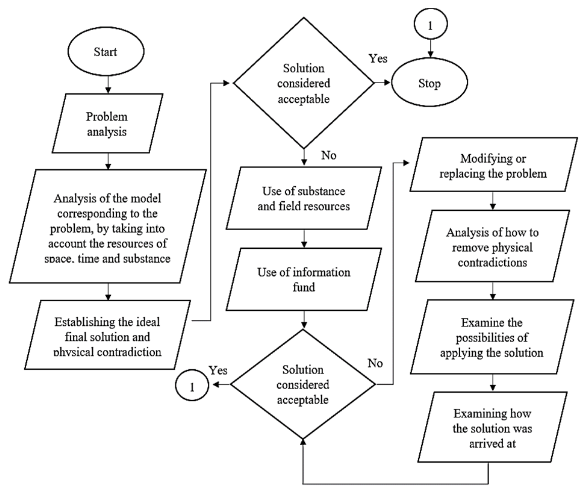

Fig. 1. Logic scheme to apply the TRIZ method.

2.1 Using some TRIZ principles to define the conflicting pair in the case of chemical engraving equipment

The so-called *mini-problem* could be the identification of technical equipment that can to engrave different metal workpieces by chemical engraving. This process involves removing material from a certain area of the piece to be machined due to the chemical reactions developed between the workpiece material and active chemical substance. In this way, various inscriptions, symbols, or images could be transferred on the processed surface. The zones that must not be affect-ed by the chemical reactions are usually covered with thin layers of material resistant to the action of the chemically active substance.

To investigate the factors able to affect the material removal rate and surface roughness resulted as a consequence of applying chemical engraving, the constructive solution of equipment schematically represented in figure 2 was used.

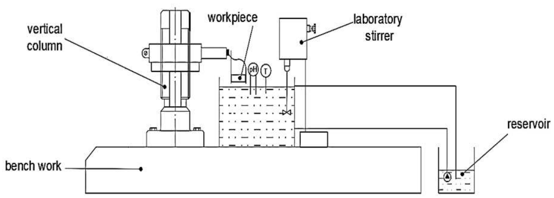

Fig. 2. Schematic representation of etching equipment.

According to the schematic representation from figure 2, the sample is immersed in an aqueous solution of ferric chloride. The aqueous solution would attack uncovered areas of the workpiece. The ferric chloride is transported to the working tank by pipes connected to a pump. The vertical column (the element that allows the part to be positioned along a vertical axis) is fixed on the work table using screws. Based on the schematic representation from figure 2, it could be concluded that *the conflicting pair* includes the chemically active substance and the workpiece (test sample) material.

2.2 Using the TRIZ principles to identify an element in the operational area to improve the performance of a milling tool

The *mini-problem* was to identify a constructive solution for a tool that could be used on a milling machine and to allow both developing a cutting (face milling) process and hardening the surface layer previously obtained by cutting.

The operating area corresponds to a milling machine. The analysis of what is in the operational area highlights the possibility of using a tool whose initial shape corresponds to a face milling cutter with several cutting teeth. The tapered tail of such a milling tool could be thus taken as a guide. This tail is necessary to position the tool in the conical hole existing in the main shaft of the milling machine. The common body of a face milling cutter can also be used.

On the other hand, in the operational area, it is known equipment that achieves the surface plastic deformation of the cylindrical workpiece using a device that could be placed instead of the universal lathes' tool holder. This device considers a tool for superficial plastic deformation (a ball, a roller, a conical diamond tip) which is pressed on the outer cylindrical surface necessary to be hardened. Some components of this device could constitute the elements that could be introduced in the operational area (milling area), effectively in the structure of the milling tool to give the possibility of materializing a hardening process.

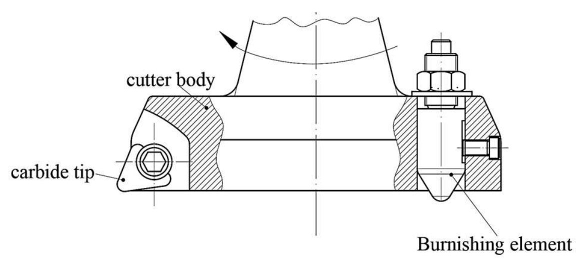

Fig. 3. The solution of a combined tool with cutting and burnishing elements.

In this way, the solution outlined in figure 3 was proposed. To remove the excess material, triangular sintered carbide inserts were used. Immediately after the action of the cutting insert, a subsystem for hardening the flat surface takes action. Essentially, this subsystem includes a bolt that is divided into three zones, a cylindrical zone, a conical zone, and a hemispherical zone. A nut facilitates the setting of the hardening tool along a direction parallel to the tool rotating axis.

2.3 Using TRIZ principles to identify an element in the oversystem able to be used to investigate the performance of a computing system

The mini-problem refers to the identification a solution to ensure various operating temperatures of the hardware component for storing information in a computer system.

It is known that *oversystems* are of great importance, as they usually directly influence the processes that take place in their components. Thus, it is desired to analyze the extent to which elements of the oversystem can be used in a system of interest. Moreover, it is considered equipment, which could be seen in Figure 4, for testing the operation of electronic devices. This equipment is used to examine the non-volatile data storage device (computer components), taking into account other temperatures than normal ones.

Figure 4 shows that the computer device for non-volatile data storage is extracted from the central processing unit and placed inside a cooling-heating box container. The latter component can ensure and high values of temperature to the normal one in the office space. The temperature inside the cooling-heating box can be changed in a previously established interval. This aspect offers the possibility to change the temperature and thus to monitor the storage component feed-back. The temperature variations of the disk operating parameters related to the ones from the box are collected and displayed on the workstation monitor using a specialized. The factors tracked with this software that could be accessed are time, read/write speed and internal temperature. Also, the error rate could be ana-lyzed or, in the case of devices with rotating disks (HDD), the possible appearance of defects on the disk surface. In the case of devices without moving components (SSD – solid-state drive), such errors will not occur because they no longer contain moving disks.

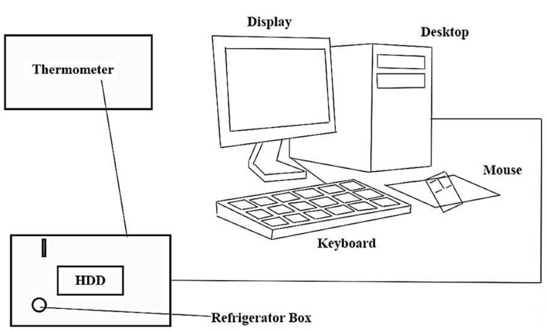

Fig. 4. System for testing the behavior of the hard disk (HDD) of a computer at different temperatures than normal ones.

2.4 Using TRIZ principles to improve the performance of the thermoforming process using FFF additive manufacturing

The problem of identifying and diminishing the influence of the factors that lead to part-shape errors or coming out of the field of roughness tolerance in the case of the molds' surfaces for thermoforming was approached. In this matter, the difficulty consists in identifying a solution for improving thermoforming mold obtained by FFF (Fused Filament Fabrication) additive manufacturing process with the limitation of the use of post-processing methods and implicitly without the involvement of other human operators.

The additive manufacturing process's *operational area* is that of the workplace that exists in a university laboratory or research center equipped with a desktop 3D printer, thermoforming equipment, and a convection oven.

Using some of TRIZ principles in additive manufacturing, it was possible to identify *the conflicting pair* represented by the mold as a workpiece and a device capable of ensuring 3D printing as a tool. It is necessary to use optimal printing parameters and ensure the decrease of printing time to increase productivity, but without a great influence on the mold's quality.

The conflicting pair elements were considered as including the thermoplastic material resistant to heat up to 200 °C and the printing system represented by the professional 3D printer desktop type. The solution must allow both to increase the processing productivity and decrease the production time by reducing the printing time and minimizing the post-processing of the mold and ensuring a low overall cost. The element used to solve the problem must contribute to the molds' realization and the parameters corresponding to a thermoforming process.

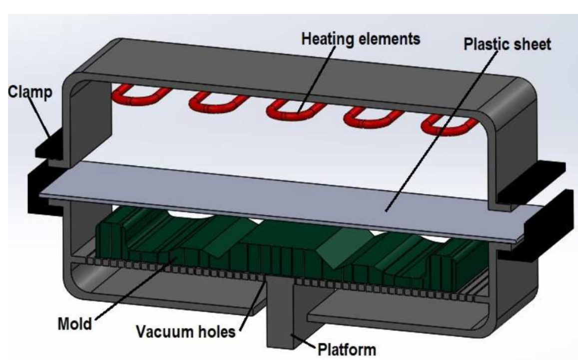

Fig. 5. Working principle for a fused filament fabrication equipment.

The ideal final solution involves the introduction of an element into the system, namely the use of a 3dkTOP thermoplastic material. It is considered that this material could be printed at a temperature of 240 ° - 260 °C for the nozzle and 80 °C-100 °C for the heated bed. These values of processing parameters can be easily materialized using a professional desktop print. The material's ability to with-stand a temperature of up to 230 °C is due to the high degree of crystallization obtained after tempering at 110 °C in a convection oven [20]

Based on the Standard ISO/ASTM 52900:2015 "Additive manufacturing - General principles – Terminology" and ASTM F2792-12A:2015 "Standard Terminology for Additive Manufacturing Technologies", there are many standardized names of 3D printing processes, that can be grouped into seven categories [14, 15]. One of the most commonly available and cheapest additive manufacturing technologies, due to the presence of the hobby type equipment (desktop 3D printer) and industrial applications, is the fused filament fabrication (FFF) as a component of the material extrusion group. A stepper motor printer that moves the extrusion head or the heated bed along specified coordinates can be used, laying the molten material onto the build plate. In this way, the melted material is seated layer upon layer, cools down, and solidifies on the build plate to form the desired part.

2.5 Use of TRIZ principles to identify the conflicting pair in the case of electrochemical equipment

The mini problem consists of identifying a technical system that facilitates the study of the characteristics of the surface layer obtained by applying an electro-chemical machining process.

Within the electrochemical machining process, two electrodes are immersed in the electrolyte solution, having the roots in what is called the electrolysis phenomenon. This process is also known as anode dissolution. Aqueous solutions of acids, bases, and salts are used as electrolytes in the electrochemical machining process. Using the first step of TRIZ method, it was possible to identify *the two technical contradictions*. One of them is to use an inductive rust meter with tracing leads to increase the productivity. On the other hand, it seems that there is a problem with the utilization of this equipment because of the large number of elements that are required to use the equipment at full capacity. The second contradiction is to use other manufacturing processes that could reduce costs, while also leading to a drop in productivity.

Minimum changes in the system are necessary to achieve the electrochemical erosion process, which is acceptable in productivity and does not require heavy physical effort from the worker. The conflicting pair is considered the electrode-as workpiece and a virtual tool, a device capable of providing a range of parameters that vary depending on the material characteristics.

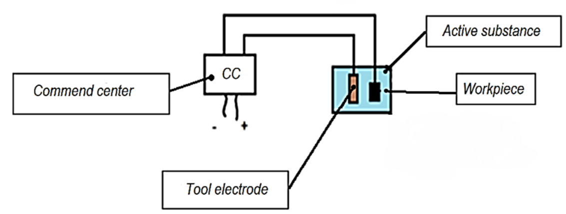

Fig. 6. Working principle of the electrochemical process.

At the limit, it must ensure productivity gains and a reduction in the operator's effort, but without a significant increase in the processing cost. Thus, there is the possibility to reformulate the problem that will take into account the elements of *the conflicting pair*: the workpiece and the system of input parameters leading to the process of electrochemical machining. The solution must enable increased processing productivity, less physical effort for the worker, and a lower overall cost.

Based on the information from figure 6, it could be described as the electro-chemical process. Hence, from the central unit Cc the required parameters are modified and transferred to the workplace through electrical conductors. Once the current source is open, the chemical reaction will happen between the workpiece and the tool electrode. By going through the previous steps, using an electrochemical erosion processing device with the possibility of changing input values has been shaped.

2.6 Use of TRIZ principles to solve the constructive contradiction of magnetic transmission

Given the fact that *technical contradictions* that appear in a system are the basis for the application of the TRIZ method [19], it will be determined the most obvious ones, resulting from the challenges and obstacles that stand in the way of using magnetic transmissions in the industry. These contradictions are as follows: the first one is considered *a high torque density ↔ high production cost*. This means that a higher torque density can be obtained by increasing the volume of magnetic material and using rare earth magnets, but this will lead to a substantial increase in the cost of production. Also, small gaps will contribute to the increase of the torque, but they will require advanced production and assembly equipment, leading to increased expenses.

The second one is a *high-efficiency ↔ wide speed range*, referring in this case to the main cause of energy losses of the magnetic transmissions which is reprezented by the "torque ripple". The last one mentioned is an effect that occurs because of the variation of reluctance. What is more, the "torque ripple" effect is substantially diminished when high speeds are reached, but when it comes to low speeds has a strong influence on transmission efficiency.

Finally, the last technical contradiction of magnetic transmissions is *multiple ratios ↔ large transmission size*. The existing magnetic transmission topologies have mainly a single torque transformation ratio (usually of reduction). The chaining of several magnetic reducers is a solution that would have large dimensions. It is necessary to find a constructive solution that has multiple transmission ratios at a small size.

The miniproblem consists of constructing a magnetic gear to ensure multiple torque transmission ratios while still having a reasonable overall size. A combination of several magnetic transmission to form transmission ratios would lead to enormous gearbox sizes. As a result of the increase in the number of gears (desirable effect), the box's dimensions also grow (undesired effect). In an ideal way, it id necessary that the magnetic transmission of small dimensions ensure a large number of transmission ratios. To achieve *the ideal final result*, the transmission must have two mutually exclusive properties: it must be small to occupy a small space, and large to ensure multiple transmission ratios. This is *a physical contradiction* to be solved, and TRIZ uses the principles of separation to solve physical contradictions, class 5 standards, and a database of more than 1000 physical, chemical, and geometric effects. The transmission ratio in a magnetic transmission is given by the number of poles of the external rotor, internal rotor, and the number of flux modulator segments [7]. By applying *the segmentation principle* and taking into account how the transmission ratios are formed, it was possible to create three segments on the internal magnetic ratio, each containing a different number of pairs of poles. The formation of the three transmission ratios is obtained by translating/sliding the internal rotor to align each segment with the outer rotor to obtain the transmission stages. The representation of the solution can be observed in figure 7.

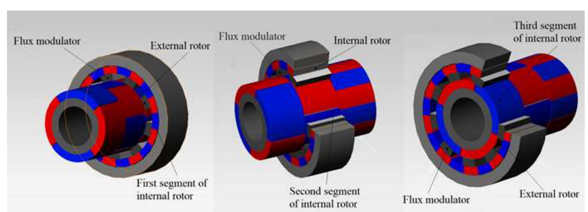

Fig. 7. The constructive solution reached by following the application of TRIZ.

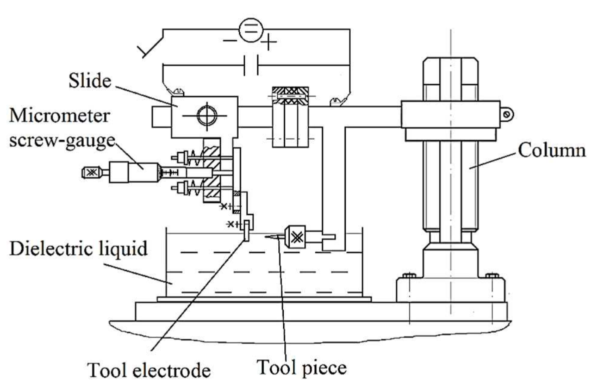

Fig. 8. The constructive solution of the device designed to allow the study of the behavior of sharp peaks under the action of single electric discharge.

2.7 Use of TRIZ principles to find out a device for studying the behavior of sharp peaks in electrical discharges

Applying the first stage of the TRIZ method, it was possible to find the *two technical contradictions*. One of them is considered to be determined by the use a vertical column in which the approach of the electrode is possible in a vertical plane as CT-1, and the use of a horizontal device in which the approach of the electrode piece is made in a horizontal plane as CT-2. The selected contradiction is CT-2, which involves a better determination of the masses of the tool electrode and test piece electrode. On the other hand, it is mandatory that the device intended to be utilized in the case of studying the behavior of sharp peaks under the action of single electric discharge, between a tool electrode and a test piece having a conical peak (with various angles of the conical peak). Furthermore, there are some conditions that will be taken into consideration to get a functional device. As a result, one of the requirements is that the designed device (fig. 8) must have the capability to facilitate the investigation of the behavior of sharp peaks under the action of single electric discharge. What is more important, the selected device must be able to ensure the conditions of immersion of the tool electrode and the conical peak of the test piece in a dielectric liquid for a better simulation of the conditions during the electrical discharge machining process.

3. CONCLUSIONS

The study of the literature has highlighted various uses of the TRIZ method to solve problems in different fields. It was appreciated that this method or at least some stages of its application could be used to solve the design and development of equipment or processes addressed in doctoral research. In this sense, it has become possible to clarify and solve particular problems in the case of the equipment and processes mentioned above. In the future, it is envisaged to continue investigating of the possibilities of using the TRIZ method to improve the equipment and process solutions approached in the case of doctoral research.

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Utilizarea unor principii TRIZ în cadrul proiectării echipamentelor de cercetare

Rezumat: Dacă în cazul proiectării de rutină a echipamentelor sau tehnologiei de fabricație, nu este necesar să se identifice și să se aplice îmbunătățiri ale echipamentelor sau tehnologiei de fabricație, atunci când se aplică designul creativ, trebuie găsite soluții îmbunătățite cel puțin pentru unele dintre obiectele proiectate. Ar putea fi aplicate diferite metode pentru a identifica modalitățile de îmbunătățire a obiectului activităților de proiectare, iar teoria rezolvării problemelor creative este un instrument util care poate fi utilizat pentru a rezolva astfel de probleme. Unele dintre principiile teoriei rezolvării problemelor creative au fost aplicate în cazurile identificării de soluții inovatoare pentru componentele echipamentelor experimentale dezvoltate în cercetarea doctorală. Astfel, a fost abordată modalitatea de definire a contradicției principale, a utilizării elementelor din zona operațională sau din subsistem, precum și fondul informațional în cazurile unor echipamente pentru fabricare sau a unei investigații științifice de proces diferite. Utilizarea TRIZ a facilitat identificarea unor modalități îmbunătățite de soluționare a problemelor de interes de cercetare doctorală.

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