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COMBINED APPLICATION OF CAXX AND DFMA TECHNIQUES IN THE DESIGN PROCESS

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ABSTRACT: Purpose – *This paper aims to present a summary about the activity of the Institute of Mechanical Engineering in the University of Pannonia on the research of the product and process design methods – supported by CAXX (Computer Aided Techniques) and DFMA (Design For Manufacture and Assembly) technologies.*
Design/methodology/approach – *The paper summarizes the main types of the requirements raised against the newly developed products as well as the production processes. In addition, this paper reviews the main optimizing methods, targets widely used to find the suitable solutions for the complex demand of the customer/owner/society. Application samples are presented to demonstrate the effective use of the combined CAXX/DFMA methods reaching the optimal solution.*
Findings – *the combined adaptation of the CAXX technologies and the DFA/DFM/DFMA modules is applicable to develop an effective product and production process design method, which can guarantee the simultaneous fulfillment of the complete specification and the fulfillment of the product level as well as the production system level optimum criteria.*
Research limitation/implication – *The specific cost data (labor cost, social expenses, energy costs) in the DFMA methodology are location dependent. This factor may limit the general validity of the results.*
Practical implications – *The usage of CAXX technologies, DFMA and optimizing methods in different product-process development projects demonstrated the adaptability of the CAXX technologies in different industrial environments.*
Originality/value – *The paper demonstrated, that the high end design methods are effective applicable not only for high volume production, but also for SMEs working with small series as well as in the prototyping procedures.*
KEYWORDS: *CAXX technologies, DFMA method, optimizing*

INTRODUCTION

Significant development can be observed almost all the particle segments of the product design and prototype development activities during the last decades. Because of the market situation all the Original Equipment Manufacturer (OEM) companies have to pay more and more attention to be competitive. Reducing the production cost, shortening the new product implementation time, and increasing the quality level and the support towards the customer; are the requirements, which cannot be negligible anymore. Because of these facts especial responsibility belongs to the product-process designers, they are the key figures of a team who is targeting to implement a new product into the production process (Figure 1).

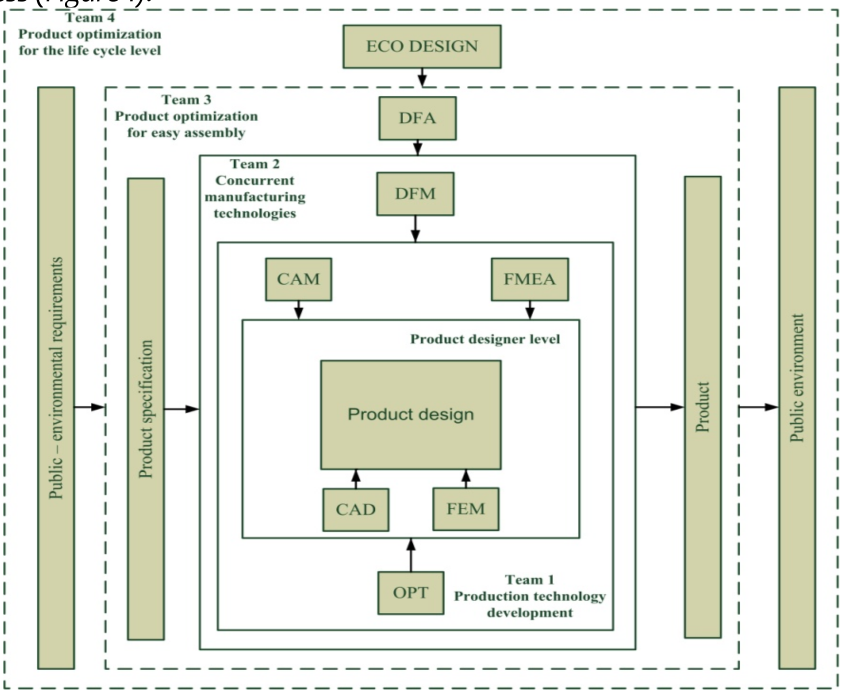

Figure 1. Product design vs. requirements vs. design techniques

Beyond the requirements for the „pure" product specification a number of other requirements are raised by the customers, the owners, as well as third party participants against the design team. Possible classification of these kinds of additional requirements is as follows:

- *Cost type requirements*
  - *minimum production cost (in order to reach the maximum profit rate),*
  - *short design and process development time,*
  - *optimum utilization of the production facility and resources.*
- *Quality type requirements*
  - *reduced number of possible nonconformities during the guarantee period,*
  - *fault free production,*
  - *increasing the guarantee period.*
- *Society origin requirements*
  - *to minimize the specific energy consumption,*
  - *to minimize or recycle the waste materials,*
  - *to minimize the maintenance need of the product,*
  - *to optimize the handling of the amortized and scrapped products . Widespread using the CAXX technologies, more and more optimizing methods and complete knowledge database were formulated in specific areas. The new computer aided engineering and management systems supports the product-technology development and project management process on a base of a common database. Although these engineering-management systems are highly complicated, the local implementation of them is based on the existing infrastructure, technology and knowledge database of the actual company.*

APPLICATION OT THE OPTIMIZATION METHODS IN THE DEVELOPMENT PROCESS

The general mathematical description of an optimization problem is defined as to minimize an objective function $f(\mathbf{x})$

$$\min f(\mathbf{x}), \qquad \mathbf{x} \in E^n;$$

subject to m linear and/or nonlinear inequality constraints

$$0 \le g_j(\mathbf{x}), j=1,2,\dots,m$$

and p-m linear and/or nonlinear equality constraints

$$0 = h_j(\mathbf{x}), j=m+1,\dots,p,$$

where $\mathbf{x}=[x_1, x_2,\dots, x_n]^T$ *the variables (design parameters).*

In the case, when the optimization problem belongs to a product or process design task, the objective function may contain the raw material cost, the manufacturing costs (machine costs, the energy costs, etc.), the assembly costs, the maintenance costs and also the costs related to the recycling at the waste handling at the end of the lifetime.

The inequality and equality constraints can be formulated as mechanical stress, or strain constraints, dimension limitation, constraints for the production technology etc.

The design parameters (variables) can be dimensions, technology parameters, physical attribute (temperature, pressure) strength parameters. The variables may have discrete or continuous distribution.

The suitable solving method for the optimizing problem can be selected depending on the actual form of the objective function and the constraints [1]. The competitiveness requirement transmitted by the social-economical environment toward the design team, incentive the product and production process designers to find the possible ways of the minimum usage of resources at the production phase. This way the product can reach a competitive position compared to other similar products. The engineers have to find those parameters of the product, which will result optimum product or/and production process and will provide a higher level competitiveness [2].

An overview of multidisciplinary optimization conceptual element was presented with two examples of MDO methodology applied to preliminary design problem [3]. Several papers were published about the development of the solving algorithms of the optimization methods. In the case of multi-objective optimization problems modified the definition of dominance in order to solve constrained multi-objective problems efficiently [4]. Simulation results of the constrained NSGA-II on a number of test problems, including a five-objective, seven-constraint nonlinear problem, were compared with another constrained multi-objective optimizers, and the much better performance of NSGA-II was observed.

The necessity of the optimization can be seen on different levels of the design/development process.

- *Component level optimization*
  - *Optimization of the geometry [5]. One of the most valuable cost factors is the material cost. Highly recommended is to design a product with the minimum usage of material (minimum*

material cost). Because of the material cost correlates to the volume of the part, it also correlates to the geometry features (i.e. the dimensions of the cross section). Finally the optimum usage of the material is equivalent with the optimization of the product geometry task. In the case of dimension (geometry) optimization often the dimensions of cross sections or geometrical parameters are computed [6]. It is recommended to use nonlinear optimization methods at the design process.

- *Shape optimization. Traditionally, in shape design of mechanical bodies, a shape is defined by the oriented boundary curves of the body and a shape optimization the optimal form of these boundary curves is composed [7]. The design method targeting to find the optimal shape of the component with the constraints, that the so called material utilization must reach the maximum level (e.g. uniform strength state component).*
- *Optimization of the engineering technology. Most of the CAM systems are equipped with routines to optimize the facility resources for the component production, for example to minimize the cutting tool movement during the production process [8].*
- *Optimization of the technology system. Some cases, when the company has some concurrent technologies to machine the component, it is questionable, which technology could result more advantageous to produce the part. The modules of the DFM/DFA/DFMA methods provide the possibility for the design teams, to compare the costs of theoretically possible technologies, and to select the most advantageous process for the serial production.*

□ *Product level optimization*

- *Optimized assembly process. The last phase of the manufacturing process, the assembly task could results valuable cost factors. The precise design job could minimize the amount (and costs) of the assembly process, if it was a preliminary targeted factor to use the minimum number of components. The DFA method could help the designers with the analysis and redesign technology in order to reach lower assembly time and of course lower assembly costs.*
- *Optimization of the production system. The actual infrastructure, the actual machinery and human resources of a company could serve the interests of the owners as well as the employees, when the utilization of the resources is uniform and optimal. It seems to be necessary to plan the optimal daily-, weekly-, e.t.d. operation all of the human and machine type resources. The precise planning of optimal production batch sizes, the structure of basic operations often requires to use optimizing methods.*
- *Optimization of the logistic system. Having a look at to the position of a company in the supply chain system, the logistic relation with the customers as well as the suppliers has special importance. The economical requirement means, that the planners have to set the parameters of the logistic systems (order structure, stock levels, production sequencing) that the long term logistic type costs should be optimal (minimal). Most of the cases these systems are extremely complicated due to several parameters. It seems to be good to use generic and/or SWARM optimization methods to handle them.*

□ *Societal level optimization*

- *Resources minimization: The design and also the production technology have to be designed that the total usage of the resources (energy, utilized land area) should be minimal, and also the minimum amount of the waste material should originated from the production process [6]. The application of the multi main function based optimizing methods is well known in this area.*
- *Product life cycle cost optimization: A valuable development process can be seen in the design method during the last decade, which is calculating with the lifetime factors of the product, for example the maintenance demand as well as the impacts of the disassembly, recycling and scrapping at the end of the lifetime [9]. The ECODESIGN optimizing methods are suitable to reach the optimum design with these conditions.*

APPLICATIONS. CAXX MODELING AND NEW PRODUCT IMPLEMENTATION METHOD FOR CASTING

The project targeted to develop a new tooling process especially for companies using unique or small series casting technologies. [10]. The time frame from the idea, up to the implementation can be reduced significantly using this method. The widely used original tooling method was based mainly on hand work with the supervision of the design engineer. The proposed technology based on the CAXX technologies, by applying CAD, FEM and Additive Manufacturing methods can support the design activity. The CAD technique supports the visualization increasing the efficiency of the early decision making points. The finite element modeling is able to follow, and eliminate the shrinking of the material during the casting process. This modeling method will reduce the implementation time eliminating several iterative steps from the tooling process. Using the Additive Manufacturing technology (3DP), the final product sample (which is the core component in the tooling process) can be made very quickly. The original and the new proposed tooling technology was compared using the DFMA analysis. The DFMA *index of the new technology decreased almost 50 percent from the level of the original tooling method (Table 1).*

Table 1. The time structure of the prototype development process in a tooling project

No	Component/operation	Time (hours)	Remark
STEP-1	CAD modelling	2.0	3D model creation using the CAD software
STEP-2	Production of prototype components	7.5	3D Printing (Rapid prototyping)
STEP-3	Measuring the prototype parts	1.5	
STEP-4	Assembly	0.5	Joining and glueing the 2 parts, finishing operations
STEP-5	Checking	0.5	
Total time with the new method		12	The time significantly reduced
Total time with the old method		18	Originated from the industrial partner

It means that the tooling process based on the application of the CAXX technologies can save implementation time and cost. The effective usage of this new tooling process was presented on the tooling process of two products with slightly different geometry (Figure 2).

Figure 2. Casting form, made with the prototype core

DFM ANALYSIS OF A GENEVA DRIVE MECHANISM

The Geneva drive mechanism is used for transforming the continuous rotating movement to periodical rotating movement (Figure 3).

The star-like component (the periodically moving part) is build up from two components, one is punched from sheet metal, and the central component is made from a bar with turning operation. The production costs of three different possible production technologies - laser cutting; plasma cutting; punching - were inspected and compared [11]. Different sensibility against the production volume was observed during the comparison. In the case of smaller series of production (up to 40000 pcs life volume), the laser cutting is the economic technology, but in the case of higher volumes production (above 40000 pieces), the punching technology seems to be optimal selection (Figure 4).

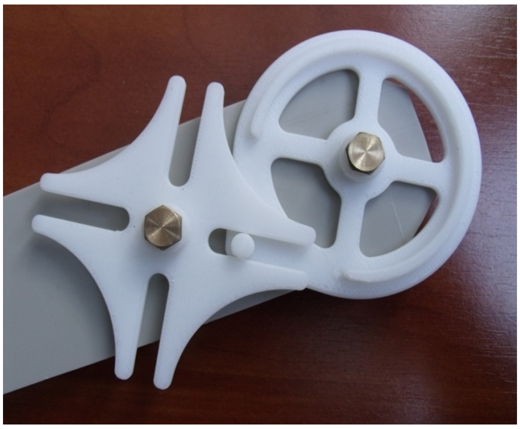

Figure 3. The Geneva drive mechanism

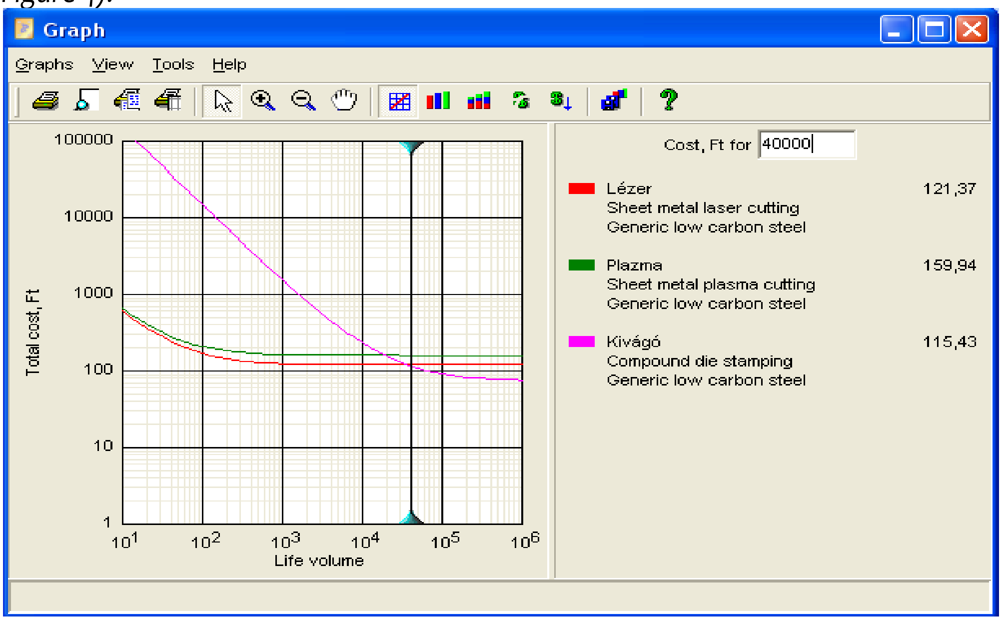

Figure 4. The manufacturing costs vs. life volume.
The actual costs data calculated for the case of 40000 pcs life volume

INSPECTION OF THE PRODUCTION COSTS OF A MOUNTING BASE

Several concurrent production technologies can be compared using the DFMA method at the design process of the mounting base described on the figure below [11], (Figure 5).

The following possible technologies were inspected:

- *production in a punching-bending tool,*
- *sand casting,*
- *injection molding,*
- *welding of different punched and bent component.*

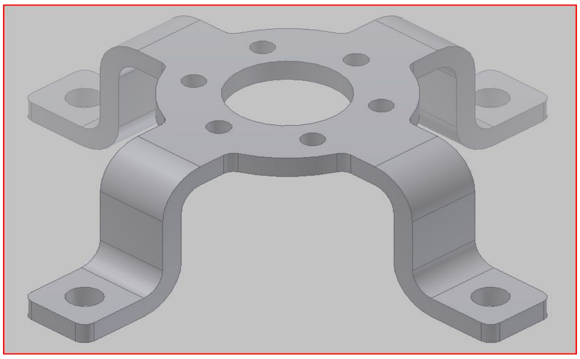

Figure 5. The mounting base

Graph

Graphs View Tools Help

Life volume 100000	Cost, Ft							Initial tooling investment
	Material	Setup	Process	Rejects	Piece part	Tooling	Total	
Hajlított Turret pressworking Low carbon steel, cold rolled, (	290,55	3,47	127,98	11,37	433,37	22,93	456,30	2 292 720
Öntött (homokforma) Sand casting, automatic Gray cast iron	17,87	16,82	459,68	7,84	502,20	39,86	542,06	3 985 777
Nyomásos öntés Metal injection molding 316L austenitic stainless steel	1 586,04	1,24	2 208,70	297,88	4 093,86	21,62	4 115,47	2 161 525
Hegesztett szerkezet Assembly fabrication Low carbon steel, cold rolled, (	134,33	9,84	582,54	7,70	734,41	2 491,47	3 225,88	1 346 741

Figure 6. Total manufacturing costs vs. life volume (10000 pcs)

All the cases were calculated not only the material and the pure manufacturing costs, but also the preparation (setup) costs, the tooling related costs and also the reject costs were considered. The calculations resulted that among all the cases the punching-bending tool usage was the most attractive technology independently from the production volume, since the total production cost was the least in this case. The cost structure is described in the case of 10000 pcs life volume (Figure 6).

CONCLUSIONS

It was demonstrated on several applications that the combined adaptation of the CAXX technologies and the DFA/DFM/DFMA modules is applicable to develop an effective product and production process design method, which can fulfill the following constraints simultaneously:

- *all the product specification (dimensions, tolerances, strength characteristics, operation parameters),*
- *the optimum criteria (minimum raw material usage, minimum operation cost belongs to every specific technology),*
- *complex optimum criteria (optimum finding on a set of possible concurrent technologies, optimum product design considering life cycle characteristics.*

The production costs of the product can significantly decrease, and competitive market position can be reached using the methods of DFA/DFM. In addition, the design of the production technology can be more precise depending on the production volume.

Since the DFA/DFMA software tool is not an open source application, than it is difficult to integrate into the optimization process and therefore one has difficulties in comparison with other optimization applications.

The Mechanical Institute on the Pannon University (Hungary) has established a CAXX (CAD, FEM, DFMA, 3DP, CAM) laboratory. Optimizing methods for minimum cost products (material-, production-, operation costs) are applied in the design process.

CAXX technologies were integrated into product development processes. Applications were presented.

Based on the results the adaptability of the CAXX technologies were demonstrated on different industrial samples.

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