Generic Product Development Process at the detailed design phase

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Abstract:

The diversity in the types of products on the market, leads us to agree that for each type of product manufactured, there is a specific methodology and a corresponding product development process. Each company may indeed have different development and design methodologies, to suit their specific needs. The complexity of the product, the competitiveness of the market and the pace of change in technology, are all factors that model the design and development processes. Remaining competitive requires from companies that they use design methodologies and production techniques that enable them to design and manufacture their products in the shortest possible time. The methodology that we have developed will focus on the achievement of some design and validation criteria (fatigue, ultimate strength, stiffness, elastic limit, etc.) The proposed methodology features four phases: 1) Data collection, 2) Analysis / Optimization, 3) Design review, 4) Validation. The first two steps represent the quantitative dimension (theoretical) of the methodology in which several alternatives are developed to meet the design criteria. Steps 3 and 4 represent the qualitative dimension (choice and validation of final solution). More specifically, the choice of a solution among several alternatives will be taken in step 3 before starting the prototyping work. In the validation phase (step 4), the designer will select the criteria and validation tools, as deemed appropriate. The methodology will also include a section on the economic impact of the price / performance ratio therefore enabling engineers to make the best decisions regarding the key design parameters (geometry, material, design). Iteration loops will provide an efficient tracking mechanism

for all the parameter changes, following the theoretical analysis and physical testing. The methodology will be applied on two different types of products (new concept and design as an evolution of an existing model)

1. Introduction

Engineering design is a process which includes developing a system, component, or manufacturing process with the desired needs. The process of engineering design is also a decision making process, in which the basic sciences, mathematics, and engineering sciences are applied to convert resources in the best possible way to meet the initial objective. For the time being, the current Mechanical Engineering curriculum at the UdeS successfully promotes the design and fabrication of functional prototypes as an outcome of the bachelor's degree. These typically express the first and most creative phases of the product development process (course IMC 156 on Design Methodology developed by F. Charron). However, in an industrial context, additional phases such as cost optimization and reliability validation have to be addressed prior to production. Such steps are often overlooked in engineering curricula despite being critical to the commercial success of a product. Achieving both on a given product is challenging since these two phases are often contradictory: Reliability involves better parts and manufacturing, whereas lower cost favors cheaper material and processes. Therefore, accurate data on product use and loading, as well as appropriate digital simulation and experimental fatigue testing become paramount in order for the design engineer to strike a balance between reliability and costs while reaching product life targets.

1.1 The impact of the design process quality, cost and development time of a product

At the beginning of the design process, most efforts are concentrated to determine the needs and understand the problem of design. At the end of the process, the activities of documenting the results are prominent. Engineers, who have no knowledge regarding the manufacturing process, will develop products that will be difficult to produce or manufacture, or these products will involve additional costs. The process of product design is a series of technical activities, included in the process of product development. These include relationships between the visions for their product and technical specifications, development of new concepts, development of product architecture, etc. Ertas and Jones, speak about a few techniques for improving the design process [1]. Thereby, **the functional cost analysis** is the technique that involves breaking the product down into its component parts and determining the cost effectiveness of the elements relative to the importance of the functions being provided. This technique allows the high cost areas of the design to be identified so that effort can be concentrated on cost reduction or enhanced functionality. Another technique used for improving the product design and which can be applied for one component, subsystem, or system level, depending on the product being designed, is **Failure Mode and Effect Analysis (FMEA)**. This approach provides a synthesis of overall product subsystems safety. Also, it identifies critical components and provides information regarding the sensitivity of product subsystems [1]. The key questions posed by this analysis regarding the impact on the quality of the product are: 1) What could be wrong with each product component? 2) What is the probability of failure and what are the consequences produced by the failure? 3) What steps should be implemented in the design process to prevent the failure? [2] The principle of the reduction of variability in the performance of the product is met in a third method for improving the design product and this is the **Taguchi Method**. To accomplish this goal towards the reduction of critical components in the product, the factors causing the variability in the product functions must be well understood so that design sensitivity to these causes can be minimized.

[1][3][4]

1.2 Product Optimization

The optimization of a product at the detailed design phase is a continuous cycle of controlled experiments on a developed product where its components or subassemblies under tests provide immediate feedback on the product design. Once this cycle is completed, engineers will choose the best options. For complex products, a stronger integration is needed between the structural analysis and other traditionally separate fields, such as aerodynamics, heat transfer, propulsion, controls and electromagnetism [5] [6]. Generally, product optimization projects are carried out by specialized engineering companies, in collaboration with industrial partners and projects revolve around three key components: Multidisciplinary team; methodologies; and technologies. Problems associated with design optimization have been the subject of considerable attention for a number of years [1]. During the last several decades the field of design optimization has made remarkable progress in system design and engineering analysis and many modern optimization methods have been developed. Thus, the design of complex systems has become possible within an optimum computational time. There are two kinds of effects associated with any product or system: 1) Undesirable effects such as large vibrations and deflections, excessive cost, low fatigue resistance. 2) Desirable effects such as long useful life of the product, good lubrication capacity, good corrosion behavior. Application of product optimization at the detailed design phase requires formulation of an objective function such as resistance to corrosion, cost, weight, or fatigue failure and the expression of design constraints as equalities or inequalities. Also, the engineers have to take into consideration in their design constraints, the requirements specified through regulations, laws as well as national and international standards, regarding the safety of product users. For example, one of these constraints could be the parameters of the light projection (angle and intensity) of an automotive headlight [1][7][8].

1.3 Product Validation

The validation phase covers all activities related to research and product development, studies of pilot batches preservation and handling of the finished and unfinished products. The validation of a product is a very important step that most often involves additional costs. Thus, engineers must take into consideration the cost / benefit ratio to decide to what level validation is needed for the new product. To respect the job safety and health standards, the engineers must be able to identify hazards associated with their work and to quantify the impact and severity of a potential failure of their designs. Thereby, a product validation algorithm, which evaluates constantly the design for safety, must be developed. The quality, safety and efficiency must be part of the product [1] [9]. Cooper speaks in his book, about the tests that can be made with customers. The product must work right when the customer uses it, not only during the laboratory tests. Thus, user tests during the development process of the design and after the prototype is ready, often prove the success of the product. Some of the main objectives of the customer tests can be to determine if the functions of the product are met in actual operation conditions and to forge a vision of the benefits, level of interest and required features of the product [7]. With the evolution of technology and the ever increasing complexity of new products, new development methodologies require more focus on design and validation criteria for new products. Thus, our efforts are focused on finding a design methodology which optimization loops will be performed for each criteria analysis. Moreover, designers can intervene on the design parameters (material, geometry and boundary shape), should an error be detected in the theoretical calculations or in the prototyping and testing phases of the design process.

2. The Objectives

The main objective of this paper is to propose a methodology for complex product design that could be used in several design situations and which will reduce the duration and costs of the design process. The proposed methodology will cover the detailed design phase and will tackle two dimensions. The

first dimension is focused on finding the best combination of material / geometry based on a performance driven criterion (stiffness, elastic deformation, ultimate yield, fatigue, etc.). The second dimension is dedicated to the validation of new products. More specifically, an important goal will be to establish a validation method to confirm the results of the theoretical and numerical analysis conducted on a given product. The originality of the proposed method owes to the fact that there are several elements and criteria proposed in the study (fracture, resistance, costs, mass, volume, etc.) Also, the optimization loops of the proposed methodology will allow the designers and managers to control the design process from the first steps of project until the final validation. The parallel analysis of multiple design criteria and several validation criteria will be used by engineers to make better decisions regarding the type of tests chosen and the level of validation for new products. Unfortunately, there are not many publications focused on complex methodologies based on multiple design types and criteria. The present research in this field at UdeS is focused on finding the appropriate methodology which validation algorithms and iteration loops will reduce the time allocated for the design process, thus helping engineers achieve the best performance/costs ratio.

3. Design methodology based on multiple performance criteria

One of the intents of the detailed design phase of the design process is to develop a system of drawings and prototypes that completely describes a proven and tested design so that it can be manufactured. At this stage, all the various disciplinary teams are actively involved in the analysis process, evaluating components, assemblies or products to validate previously established requirements for the new product.

Integration of product optimization in design processes

One important step in evolving from a prototype to a product is that of optimization, where engineering choices are made to reduce production costs while at the same time maintaining the functionality and attractiveness of the product. However, this entails

specific engineering knowledge and tailored methodologies. More specifically, product structural optimization starts with the proper identification of critical load cases on a given structure or product and involves the choice of appropriate material and geometrical parameters as variables to achieve some performance target. These in turn translate as optimization criteria with appropriate safety factors. Typical optimization criteria include resistance (S_u or S_y), rigidity and product fatigue life expectancy. Criteria based on the ultimate strength (S_u) are seldom selected but examples of their use include the design of bolted joints. Resistance criteria based on the yield strength is most common as it implies that the designer will not allow the part to accept permanent deformations under load. Rigidity is more stringent than resistance as it limits the amount of allowable strain. This is typically specified for sports cars where handling performance requires a frame with high stiffness. Finally, fatigue life target is often selected in a bid to limit costs while meeting product warranty periods.

Moreover, the optimization procedure must adapt to the type of development at hand, whether it is for a new product or the evolution of an existing model. In the case of a new product, load cases may be tricky to identify for lack of experimental data supporting the design requirements. Hypotheses and predictive models, both theoretical and numerical, must then be used to fill that gap. In the case of the evolution of an existing product, either from the same company or from a competitor, current product model performances may be used as a benchmark for the product to be designed. Alternatively, experimental testing on a comparable existing product may provide the required data and corresponding validation procedure to support the design process. All of these elements must be taken into account in the development of specific design methodologies and corresponding validation procedures to be subsequently integrated in the “product optimization and validation” procedure that is being envisioned. Surprisingly, and despite the obvious strategic and technical interest these aspects of design may bear, there is very little to be found in the way of publications on these subjects. [1][5][10]

As mentioned above, the first goal of this project is to propose a new design methodology, taking into account the geometric parameters, material criteria,

but also the validation conditions (physical tests). In figure 1, a new methodology generally applicable to a wide range of products is presented. Indeed, optimization concepts will be based on specifications taken from the product requirements, after analyzing the range of solutions based on the criteria established by the engineers. It can be observed in the section of tests and validation of the methodology that the optimization can be done taking into consideration either the safety factor or the loads. The proposed methodology covers chronologically all steps required in the design process to achieve the intended result. Thus, in a first step of census data, the design team will be formed and will establish the design tools, product requirements and the needs of the client. At this stage, the initial design parameters and performance criteria that will be analyzed (fatigue strength, the ultimate limit, stiffness, etc.) must also be established. The methodology continues with the second stage, which will be dedicated to the analysis of the performance criteria selected. This step will contain two iteration loops that will allow designers to make better choices regarding the three design parameters: material, geometry and design, while taking into account the price / performance ratio. Based on the results obtained from the analysis criteria and the constraints established at the beginning of the process, adjustments on the geometry of the product, or (if applicable) material changes can be made. These first two steps represent the quantitative dimension of the methodology in which designers will perform calculations and analyze criteria to find several eligible solutions before submitting them to the economic analysis. In a third step, the engineers will be able to take the final decision on the performance parameters. At this point, it will be a meeting with the client or the company management team (for products developed 100% in one company). After receiving approval from the client, the team can proceed to the execution of 2D drawings and prototypes. Once the prototype is completed, it will undergo tests to validate the product. Each product type requires different validation tools and the engineers must develop algorithms for specific validation types that should be addressed (fatigue testing, stiffness test, ultimate strength test, etc.). In this final stage of the methodology, another optimization loop will allow the designer to optimize the loads or the safety factor.

Thus these main stages of the methodology will allow for the design, optimization and validation of the product.

Figure 1 General methodology for the design engineering process

The first two steps or gates of the methodology, which represent the quantitative dimension, are then followed by steps or gates 3 and 4 (Revised Design and Validation); the qualitative dimension. In other words, the qualitative methodology is used by the engineers to reach the best decisions for achieving the functions envisaged for the product design. Implementing this approach with examples and applications is an original way to provide the students with the necessarily skills and feedback for their future activities as engineers.

4. Conclusions:

The proposed design approach features several key contributions to the process of product development. Hence, a general methodology focusing on several performance criteria allows the designer to optimize the design parameters after each phase of the design process. This, in turn, generates a reduction in the time required for the concept development stage. The

designers will also be able to find the most reasonable combination of geometry and material for the new product. The section dedicated to the complete validation of new products allows engineers to monitor the achievement of each performance criterion chosen (stiffness, tensile strength, durability, cost, etc.). Thanks to the validation algorithm developed within the proposed methodology, it will always be possible to maintain a connection between the theoretical analysis of the chosen criteria and the results of the physical tests. Thus, the iterations in the design process will be completed more quickly. In this domain, there are works that present the design process and the process of product development, but very few present methodologies addressing several simultaneous design criteria and containing sub-algorithms such as those for the conversion of materials or for product validation. A material conversion algorithm applied to aluminum has been developed by Pepin in his master degree thesis “*Development of a conversion methodology for structural parts from steel to aluminum*” [12]. These types of sub-algorithms are used to help designers in their efforts to optimize and validate a product and will be addressed in future works. In other words, the detailed design methodology developed here opens the way for the development of other methodologies and algorithms more specifically targeted toward precise design situations (new product, improvement over an existing product, material conversion, and validation algorithms). In some future works, the proposed methodology will be applied on real design cases to prove its relevance.

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