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Engineering Design at Concept Stage for a Front Axle Design – A Case Study

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Abstract

Now-a-days, in an industrial growth, cost and quality production in time as well as quality improvement are of major interest in engineering design. Therefore, in order to make a decision as early as possible and according to the product specifications, mechanical analysis is used more and more, and earlier and earlier in the engineering process. Then, a multitude of mechanical models are elaborated during engineering design, and management difficulties appear with engineering changes or evolution of specifications. Moreover, when the designer is faced with design or modelling options, previous analysis could answer the choice of options for decision making. Then, the reuse of a previous analysis must be envisaged.

The paper presented the aim and the different use of mechanical analysis in engineering design. Afterwards, different levels of models handled by the designer during the engineering process are proposed. The present case study will show the utilization of engineering design through 3D CAD at the concept design stage of a highly complicated shaped product for a new system.

Keywords: Engineering design; 3D CAD; Product development; Modelling; Analysis; Simulation

Introduction

Reduction of cost and improvement of quality are of great importance in an industrial context. Analysis is often used in order to make the best decisions as soon as possible in the engineering design process. On the one hand, knowing that 80% of the final product cost is fixed during engineering design, each decision in the design process must fit at best the product requirements. On the other hand, with time to market being one of the major factors in a product's success, the length of time of the different stages of product development, and in particular engineering design, has to be reduced. Good design options must be chosen at the earliest stages, in accordance with the required specifications [1]. However, when engineering changes occur, the modification of the design has to be controlled in order to limit lost time. This control depends on knowledge of the linkages existing between the different product patterns in order to keep consistency of the whole representation of the product [2]. Another way to save time could be systematic use of a reusable analysis library [3]. This reusability depends both on the tracks of the first analysis and on the accessibility of these tracks. A way to face this problem is to structure the information handled during design and analysis in order to facilitate the control and reuse of multiple models.

Mechanical Analysis in Embodiment Design

Engineering design is a process of creation that transforms a need into a product. It is characterized by its complexity and the multitude of jobs and actors it implies. When a requirement list is elaborated and a principle solution is chosen, the construction of the structure can be divided in two steps: first, its development, i.e. preliminary layouts and form designs and, second, its definition, i.e. detailed layouts and form designs [4]. For embodiment design, best layouts must be chosen. Then, refinement and improvement of the structure is necessary related to technical criteria. Thus, in order to select and to evaluate solutions, mechanical analysis is required in the design process.

Mechanical analysis can then be used either for validating, dimensioning or simulating product behaviour. Most of the research studies on links between analysis and mechanical design deal with the integration of analysis and CAD [5]. Major problems are identified as data transfer and modeling between a single geometry and a single analysis model [6,7]. Data modeling is proposed to link the analysis model and the design model (geometric representation and technologic parameters) during the design process. However, the mechanical analysis activity in engineering design is characterized by a multitude of possible models, a multitude of existing methods and a multitude of available tools. In an industrial context, a significant challenge is the management of the multitude of analysis models generated in the project dynamic. This management of analysis in engineering design is concerned not only with the use of the different models in a project [8], but also with the reuse of older analyses from other projects within the current project. The correct use (in the case of design changes) and reuse of analysis requires intelligent tracking of the choices made during design. In particular, the design options related to mechanical constraints must be identified and referred to mechanical analyses that allow validation of the choice. Moreover, the reuse of knowledge acquired by older simulations is current for the designer [9].

The Different Uses of Analyses

The use of an analysis depends on its final goal. Three types of uses can be distinguished:

1. Analysis for validation,

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2. Analysis for aiding decision making,
3. Analysis for understanding.

Analysis for validation

Analysis for validation simulates the quantitative behavior of the structure. It permits verification if the choices of design agree with the specifications of the requirements list. For example, when the design of a new chassis has been completed, the shell model presented is used in order to calculate the global stiffness (validation of the first requirement to improve the rigidity under torsion and bending loads) and the maximum stresses in the structure (validation in terms of resistance of the design).

Analysis for aiding decision making

Analysis for aiding decision making aims to evaluate the influence of different design options on the functional structure behavior. To illustrate, the effect of section topology on maximum displacement of a bending structure is an analysis that helps to decide which section is well adapted to verify the first requirement in terms of rigidity. An analysis for decision making must engage low costs in terms of materials and complexity. Analysis for decision-making is also, for example, a stress analysis that provides tendencies of design parameter influence.

Analysis for understanding

Analysis for understanding has, as a major target, the understanding of the behaviour of the structure, for later use of the knowledge generated by the analysis. For example, when a prototype breaks in testing and failure was not expected and not understood, analysis is often driven in order to provide understanding of the structural behaviour for prevention of failure. For chassis analysis, an important difference has appeared between the expected stiffness and the one measured on the prototype. By using specific calculations, after an analysis of the mechanical assumptions, the influence of the U-sectional elasticity links has been evaluated. It has been proved that, because of the short length of the joints, local strains appear and explain the difference between the experimental and analysis models.

All three kinds of analyses provide knowledge: however, both the analysis for validation and the analysis for aiding decision making are directly linked with specifications of the requirements list, whereas the analysis for understanding is independent of the requirement list. Currently, the main tools and methods for mechanical analysis developed are well adapted for validation only. However, in industrial use of analysis in engineering design, analysis for aiding decision making is of great importance even if rarely formalized.

Reduction of production lead times is also becoming an essential requirement. In conventional product development, the conceptual design department produces sketches and 2D drawings based on 3D models of the product, and passes these drawings over to the mechanical design department. In such an organization, it is impossible for the conceptual and mechanical design departments to share a common database of information related to the shape of the product. 2D drawings not only convey the original design concept poorly, but they are also inadequate when used to convey and confirm the designer's intentions, or for decision-making purposes [10]. These circumstances have engendered a need to communicate design ideas by means of computers, to construct environments with a common database of shape information, and to use computers to conduct design simulations and presentations so as to enhance the effectiveness and quality of design processes. In line with these we have developed a complicated shaped product using 3D CAD software in three-dimensional shapes, which can be easily understood by the layman/operator. Mechanical design and production departments in later stages of the product cycle can use this.

CAD Technology and Model

Computer aided design refers to the design process using sophisticated computer graphics techniques backed up with computer software packages to aid in analytical problems associated with design work The 3-D models created on a CAD system with the help of curves and surfaces. Those curves and surfaces are generally NURBS [11]. Wire frame models are used as input geometry for simple analysis work such as kinematics studies, surface models are used for visualization automatic hidden line removal, and animations, solid models are used for engineering knowledge and visualization and are mathematically accurate description of the products and structures. The solid model can be shaded to improve visualization of the product, structure, and physical models are automatically generated from the geometric models through rapid prototyping technology.

The design model

The design model contains the geometrical and technological representations of the product. It brings the geo-metric and technologic support required by analysis. Moreover, constraints on the design parameters belong to the design model. They are an operating form of the criteria available in the requirements list and represent a step towards the formulation of the analysis goal. The design model is characterized by strong evolution dynamics. The chassis design model is shown in Figure 1, and the constraints on the design parameters are given in Table 1. Notice that, in a reengineering process, another way to feed the analysis is to use the actual product (or a prototype for a testing department) and use it to generate a model for analysis.

The mechanical model

Based on the design model of the product, the analyst (engineer or designer) builds a mechanical model. Its geometric representation is deduced from the design model by an idealization step. In other words, the geometrical representation of the design model is usually topologically modified to build the mechanical model. Complementary data such as loads, boundary conditions and material behaviour are added to obtain the mechanical model, which is a representation of the product from a mechanical behaviour view point: this model is independent of an analysis method or tool. The process leading from the design model to the mechanical model is managed by mechanical

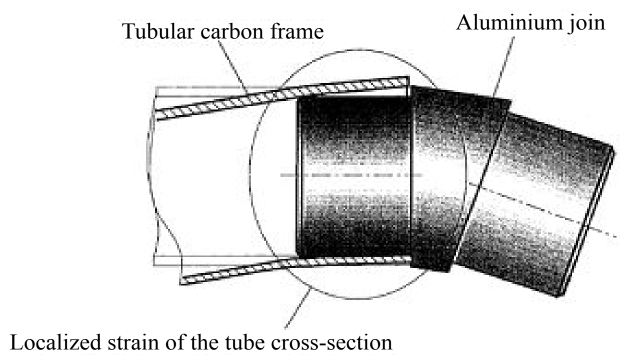

Figure 1: A typical Chassis design model.

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Function	Appreciation criteria	Influential elements	Comments and features
Improve the rigidity	Chassis stiffness	Material geometry	Reduce displacement under the driver load and in turning situation
Reduce fuel consumption	total mass	Material chassis component section	
Add a roll bar	Aerodynamic resistance Dimension mechanical strength	Projected frontal face Height, width Material fixing geometry	Respect the race regulation protect driver in case of accident

Table 1: Extract of the functional model of the chassis.

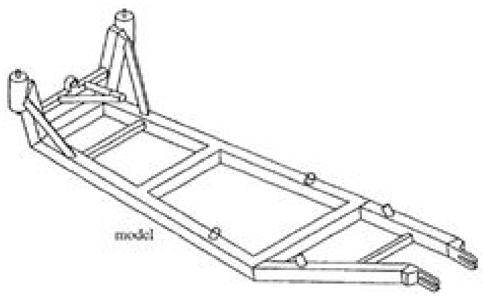

Figure 2: Mechanical model.

hypothesis, and uses the analysis goal. This process requires persons highly qualified in both analysis and design.

Figure 2 shows an example of such a mechanical model that was used during the chassis design process. This model is associated with the goal of simulation: computing with great accuracy the displacements of the whole chassis under torsion conditions. The model includes an idealized geometrical model of the chassis derived from the geometrical part of the design model, modelling of the applied loads and boundary conditions related to the situation under study, and mechanical assumptions concerning the behaviour of the structure: standard beam theory and homogeneous isotropic material, all of these features being in agreement with the objective under consideration.

The simulation model

Once the mechanical model is built, an analysis method and, then, an analysis tool can be associated with the mechanical model to provide the simulation model. It represents the product for the method and the tool in use for the analysis. For instance, the use of a finite element method implies a geometric description as a set of elements connected with nodes. Analysis parameters such as the convergence step are added to achieve the computation. In the chassis design example, both the static stiffness and the first five vibration modes must be evaluated. A typical simulation model has shown in Figure 3.

Model Creation

In CMERI we have developed the 3D model of a front axle, which was used in the front axle assembly of a small tractor through CAD, using CAD software. This model was developed keeping in mind that the model should withstand the static load as well as the dynamic load of the system.

Initially the conceptual design was made which using Auto CAD software. After the conceptual design, the detail design and drafting was made. Using high capacity 3D software, 3D CAD model generated for getting the proper visualization of the product to be made through fabrication. This model was then analyzed using Analysis software to examine whether the product will be capable of carrying the load while the vehicle is in static and as well as in dynamic condition. This analysis is also important for optimization of the design for a front axle part. The goal was to minimize the mass of the part while maintaining the same stiffness and strength as an existing axle. After making the model the same was checked virtually for fitting in the assembly. The product was from the 3D Model later on through different machining operations like Milling, Jig boring, Grinding etc. Creation of 3D Model helps a lot to the operator for making the product with a very short time. The 2D model of the front axle has shown in Figure 4 while the 3D model has given in Figure 5.

Model analysis and result

The model of the front axle was created using 3D CAD software. This model was analyzed using the finite element analysis software to find out the Von mises stress and the displacement. Maximum Von mises stress was found to be 109 MPa while displacement was 5.6 mm. As the stress is within the Yield stress of the material (350 Mpa), the design was found to be safe. The stress distribution has given in Figure 6 while displacement analysis has shown in Figure 7. The developed front axle has shown in Figure 8.

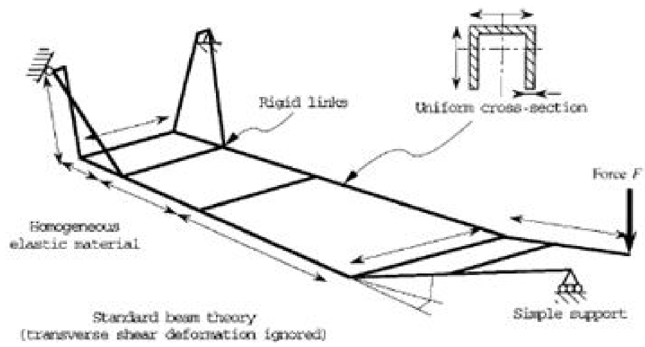

Figure 3: A simulation model.

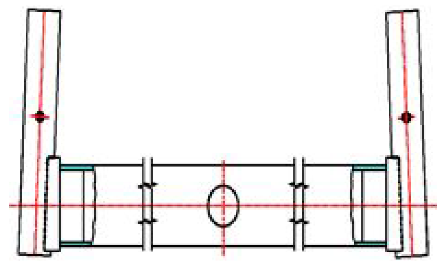

Figure 4: 2D model of the front axle.

Figure 5: 3D model of the front axle.

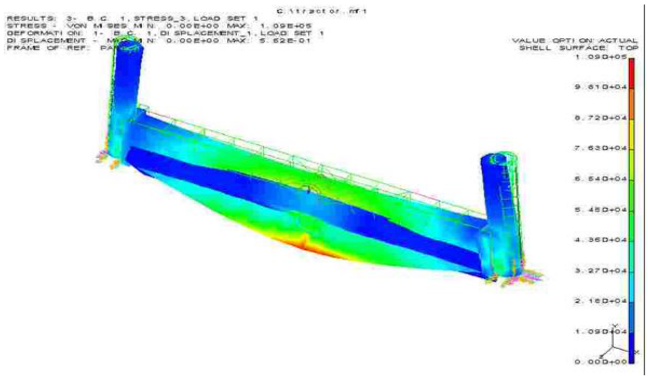

Figure 6: Stress analysis.

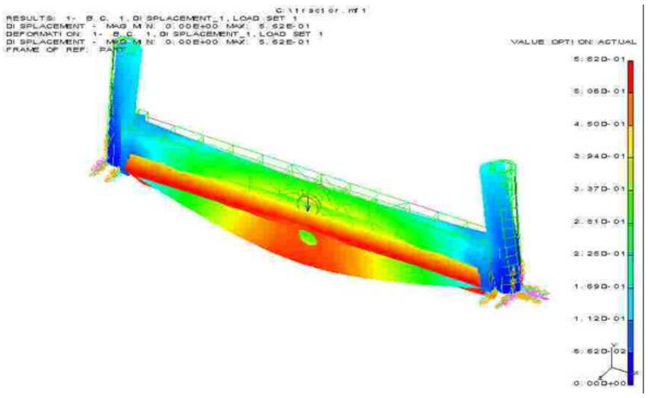

Figure 7: Displacement analysis.

Figure 8: Developed front axle.

Conclusions

Mechanical analysis in an engineering design process involves the use of many models. Four main classes of models were identified: functional models, design models, mechanical models and simulation models. The importance of two particular uses of analysis, the so-called elementary case and simplified case, was emphasized. On the one hand, the purpose of this work is to provide a formal aid to mechanical modelling. In this case study we have developed a front axle using 3D CAD software followed by analysis. This analysis was important to check the breakage/damage of the axle during static and as well as dynamic condition.

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