OPTIMIZATION PROCESS FOR LIGHTWEIGHT MODULAR AUTOMOTIVE COMPONENTS

EHSAN SHAHBAZI

A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master of Engineering (Mechanical)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

JUNE 2014

To my beloved parents and my dear brother and sister, for their endless support and encouragement.

ACKNOWLEDGEMENTS

First and foremost, I would like to express heartfelt gratitude to my supervisor Prof. Dr. Mohd Nasir Tamin, for his patience, advice and constant support throughout this project. Without his continuous support and patience this thesis would not have been the same as presented here.

The Last but not the least a warm gratitude and sincere appreciation to my beloved family and peers for their endless support.

ABSTRACT

This research is based on a design process flow, which deals with the improvement of the current way of using computer based topology and shape optimization techniques. The objective is to integrate Topology and Shape optimization with the numerical optimization techniques in order to obtain superior designs. To this purpose an improved design process is introduced to overcome the limitations of the current trend in design. The effectiveness of the proposed design process is evaluated through a design problem in which a selected automotive component is chosen to be optimized for weight and stiffness. It is seen that following the proposed approach in design can result in better solutions thanks to the invaluable gradient information that the numerical optimization part of the design process provides.

ABSTRAK

Kajian ini adalah berdasarkan aliran proses reka bentuk, yang memperkatakan tentang kaedah semasa penggunaan topologi berasaskan komputer dan teknik pengoptimuman bentuk. Objektifnya adalah untuk mengintegrasikan Topologi dan Bentuk pengoptimuman dengan teknik-teknik pengoptimuman berangka untuk mendapatkan reka bentuk yang lebih baik. Untuk tujuan ini, satu proses reka bentuk yang lebih baik diperkenalkan bagi mengatasi keterbatasan dari trend semasa dalam reka bentuk. Keberkesanan proses reka bentuk yang dicadangkan itu dinilai melalui satu kajian masalah reka bentuk di mana sebuah komponen automotif dipilih untuk dioptimumkan bagi mengurangkan berat badan dan ketegangan. Hasil menunjukkan bahawa kaedah yang dicadangkan memberikan penyelesaian yang lebih baik kerana hasil maklumat yang tidak ternilai disediakan oleh pengoptimuman berangka proses reka bentuk.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABELS

CHAPTER 1

INTRODUCTION

1.1 Introduction

Optimization technique –having been used successfully in many science and engineering problems– is a specialized mathematical method which aids scientists in achieving optimum results more efficiently. Mechanical engineering in general is one of the fields in which this technique is widely used to achieve optimum designs. Thanks to this superior technique, mechanical engineers are able to more scientifically study the problems and achieve noble solutions which are very difficult or even impossible to get if these techniques are not to be used.

This method has provided engineers with a reliable tool to cut the expenses and time of design process through achieving the final designs with less experimental trial and error.

This chapter would provide the interested reader with a background of the study, statement of the research problem, objectives, scopes, and finally the importance of the study.

1.2 Background of the study

The automobile industry has recently succeeded in building lighter vehicles which can be equipped with more energy efficient engines in order to meet the legal

requirements in reducing fuel consumption. Considerable reduction in fuel consumption and CO_2 emission is the immediate outcome of such developments. On the other hand, increasing demand for Electric and Hybrid Vehicles during the last few years has derived more attention to development of lightweight automotive structures (SUN Hongtu, et al 2010).

Modularization and common part strategy is another concept which has gained considerable attention nowadays. It is widely recognized as a cost saving and production tool in automotive and airline industry. Modularization in product design was introduced to address the customer's great tendency towards ordering personalized cars. Automotive manufacturers also show a clear tendency in providing their customers with a full product range to respond to changes in demand and reduce the risk of being threatened by the possible collapse of one market segment. Although the variety of products is a desired effect, there are some undesired side effects which the old-fashioned approach of production cannot address them. Modern modularization concepts, in contrast, suggest building more complex modules which can be widely used in many different vehicles (Parry & Graves, 2008).

In order to address both lightness and modularization issues, a conceptual design of a lightweight modular chassis for an electric car was designed by Ali Farokhinejad as part of the RUG Flagship Project 00G42 (Figure 1.1). Since the chassis is intended to be used in an electric car, the lightness of the structure is of greatest importance which is the main purpose of this project.

In addition to lightness and modularization issues, efficient design of the structure and automotive components is a key factor in improving the performance of a vehicle. There are a number of factors which shall be considered in the design of automotive components. A chassis frame, for example, shall provide rigidity for accurate handling, mounting points for suspensions, seating for occupants, steering mechanism, etc. While the required functions are fulfilled, these components should be light enough to reduce inertia and provide desired performance. These components should be designed strong enough to resist fatigue loads also.

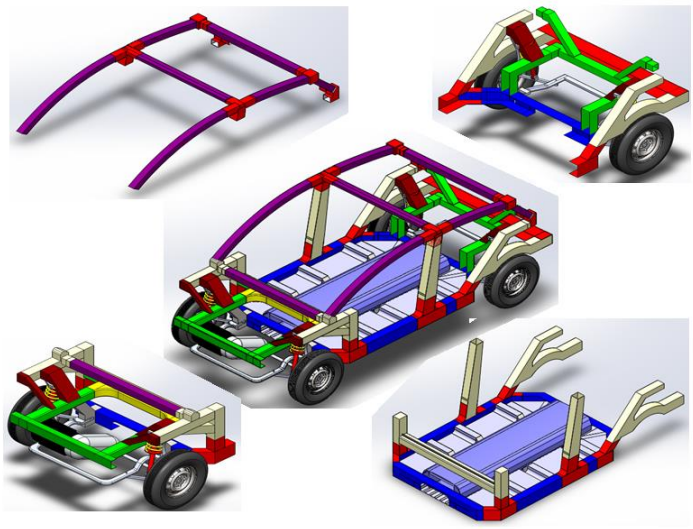

Figure 1.1 Conceptual Design of a Modular Chassis (Designer Mr ALI FAROKHINEJAD, Founded by RUG Flagship Project 00G42)

Efficient design of the structure and automotive components is best achieved through optimization techniques. Due to geometry and occasionally material complexities, numerical and finite element techniques are widely used in the design. Although mathematical modelling of the optimization problem is usually a great challenge, it is worth being worked on for the invaluable gradient information it provides. Since there are some complexities regarding the geometry and material, a more accurate optimization model is achieved if the derived model is coupled with the FE solver in case finite element analysis provides more accurate solutions.

In this project, a process flow for optimization of lightweight automotive components will be established and validated through optimizing a lightweight modular joint.

1.3 Statement of the problem

In any optimization problem the main challenge is efficiently optimizing the objectives to find the optimum set of variables. In optimization of lightweight modular automotive components the problem is even more complicated; here

optimization is only part of the problem and maybe the most straight forward part of the problem. There are several other important issues which need to be considered before the optimization phase is started including modularity and lightweight concepts which need to be overcome in the design process.

The modularity concept is the first issue to address. First we need to identify modules which are necessary and can be found in all product versions. Since modularization is situation specific, it cannot be described in process and would be considered in a case study.

Lightness of the components is the second issue to consider. Lightweight materials with high strength to weight ratio have great potential in achieving this goal. However, the problem is finding the optimum material which can only be achieved through optimization techniques.

The last but not the least is combining different optimization techniques to achieve the required objective which is the lightest component.

1.4 Objective

The objective of this project is introducing a validated process flow for lightweight modular automotive components.

1.5 Scopes of the study

The scope of this project includes the following aspects:

- Modularization Concepts in designing automotive components
- Lightweight structural materials (HSS, Al, FRP Composites)
- General Optimization Problems

- Structural Optimization techniques used in the Design Process
- Detailed 3G Optimization of a Modular Joint

1.6 Importance of the study

Lightweight Modular Automotive structure is not a new concept but it has gain considerable attention nowadays due to environmental issues and fuel crises. No one questions the fact that the lightest possible structure is achieved if and only if advanced design techniques are used. Optimization techniques which have proved their great potential in achieving optimum solutions are an important part of the advanced design processes, through which one can achieve a lightweight structure more efficiently. Although optimization techniques have been widely used in structural optimization for many years, it seems that the current way of using available optimization techniques needs to be reconsidered and a more efficient process flow needs to be established. It is hoped that this research would help mechanical and automotive engineers in getting familiar with the modularization concepts and lightweight materials. It is also expected that this research would provide a better understanding of the importance of optimization techniques as a reliable tool in Mechanical Engineering.

1.7 Structure of the thesis

After an introduction to the current problem, chapter 2 involves some of the literatures reviewed and provides the reader with a general understanding of the modularization and lightness concepts, general optimization problems, structural optimization techniques, and some case studies in which the mentioned concepts were used. After some of the theories behind optimization are introduced in chapter 2, the methodology used in this research and the established process flow for optimization of lightweight modular automotive components is explained in chapter 3.

For illustration purposes of the established process flow, a joint of the conceptual chassis presented in Figure 1.1 is chosen. Then the modularity concepts besides optimization for maximum stiffness and lightest design which satisfies design requirements, based on the process flow is presented in chapter 4.

Finally a conclusion is made in chapter 5 through comparison of the mechanical characteristics of the new lightweight modular joint with the old design.

REFERENCES

Aluminium Automotive Manual. (n.d.). Retrieved from www.eaa.net/aam

Ashby, M. F. (2005). Materials Selection in Mechanical Design (Third ed.). Elsevier.

Bartz, W. (1993). Aluminium materials technology for automobile construction. London: Mech.Eng.Publ.

Bendsøe, M. P. (1995). Optimization of Structural Topology, Shape, and Material. Verlag Berlin Heidelberg: Springer.

Bendsøe, M. P., & Kikuchi, N. (1988). Generating Optimal Topologies in Structural Design using a Homogenization Method. Computer Methods in Applied Mechanics and Engineering, Vol. 71, No. 2, pp.197-224.

Bendsøe, M. P., & Sigmund, O. (2003). Topology Optimization, theory, methods and applications. Springer.

Cantor, B., Grant, P., & Johnston, C. (2008). Automotive Engineering: Lightweight, Functional, and Novel Materials. CRC Press, Taylor & Francis Group.

Cantor, B., Grant, P., & Johnston, C. (2008). Automotive Engineering: Lightweight, Functional, and Novel Materials. CRC Press, Taylor & Francis Group.

Cheng, H.-C., Kikuchi, N., & Ma, Z.-D. (1994). Generalized Shape/Topology Designs of Plate/Shell Structures for Eigenvalue Optimization Problems. Proceeding of ASME International Mechanical Engineering Congress and Exposition , PED, Vol 682, pp. No. 2, pp. 483-492.

Diaz, A. R., & Sigmund, O. (1995). Checkerboard Patterns in Layout Optimization. Structural Optimization, vol. 10, pp. 40-45.

Eschenauer, H. A., & Olho, N. (2001). Topology optimization of continuum structures: A review. Appl. Mech., vol 54, No.4, pp. 331-390.

Eskildsen, K. (2011). Modularization. International Technology Management. Copenhagen: Aalborg Universtity.

Fonseca, J. (1997). Design of Microstructures of Periodic Composite Materials. Ph.D. Thesis, The University of Michigan.

Frecker, M., Ananthasuresh, G., Kikuchi, N., & Kota, S. (1997). Topological synthesis of compliant mechanisms using multi-criteria optimization. Journal of Mechanical Design, ASME Transactions, Vol. 119, No.2, pp. 238-245.

Hirsch, J. (n.d.). Automotive Trends in Aluminium - The European Perspective. (J. M. Nie, Ed.) ICAA9, 1, pp. 15-23.

Hirsch, J., Bassan, D., Lahay, C., & Goede, M. (n.d.). Aluminum in innovative light-weight car design. Lightweight Vehicle Structure Conference.

Keeler, S., & Kimchi, M. (2014). Advanced High-Strength Steels: Application Guidelines Version 5.0. WorldAutoSteel.

Kelkar, A. (2000). Analysis of Aluminum in Auto Body Designs and its Strategic Implications for the Aluminum Industry.

Kikuchi, N., Nishiwaki, S., Fonseca, J., & Silva, E. (1998). Design Optimization Method for Compliant Mechanisms and Material Microstructure. Computer Methods in Applied Mechanics and Engineering, Vol. 151, pp. 401-417.

Kikuchi, N., Suzuki, K., & Fukushima, J. (1991). Layout optimization using the homogenization method: generalized layout design of three-dimensional shells for car bodies. in: Rozvany, G. I. N., ed., Optimization of Large Structural Systems, NATO-ASI Series (Berchtesgaden) 3, pp. 110-126.

Klarbring, A., & Christensen, P. W. (2009). An Introduction to Structural Optimization. Solid Mechanics and its Applications. Springer Science + Business Media B.V.

Kragtwijk, N. (1998). The Application of Steel and Aluminum in a New Lightweight Car Body Design.

Lahaye, C., Hirsch J., Bassan D., Criqui B., Urban P., Goede M. (2008). Aluminium Alloys, Their Physical and Mechanical Properties. In Hirsch J. et.al (Ed.), ICAA11, (pp. 236-237). Aachen.

Ma, Z.-D., Kikuchi, N., & Cheng, H.-C. (1995). Topological Design for Vibrating Structures. Computer Methods in Applied Mechanics and Engineering, Vol. 121, pp. 259-280.

Ma, Z.-D., Kikuchi, N., & Hagiwara, I. (1993). Structural Topology and Shape Optimization for a Frequency Response Problem. Computational Mechanics, Vol. 13, No. 3, pp. 157-174.

Ma, Z.-D., Kikuchi, N., Cheng, H.-C., & Hagiwara. (1995). Topological Optimization Technique for Free Vibration Problems. ASME Journal of Applied Mechanics, Vol. 62, pp. 200-207.

Mills, A. (2002). Development of a Carbon Fibre Composite Ultra Lightweight Vehicle Structure for the Aero-Stable Carbon Car – Fastframes.

Nikkei Mechanical. (1998). Vol. 12, No. 531, 17.

Nishiwaki, S., Frecker, M., Min, S., & Kikuchi, N. (1998). Topology Optimization of Compliant Mechanisms Using the Homogenization Method. International Journal for Numerical Methods in Engineering, Vol. 42, pp. 535-559.

Ota. (1995). Total Life Cycle Conference & Exposition.

Parry, G., & Graves, A. (2008). Build to order: the road to the 5-day car. Springer.

Rozvany, G. I. (2000). Aims, scope, methods, history and unified terminology of computer aided topology optimization in structural mechanics. Struct. Multidisc. Optim., Vol. 21, pp. 90-108.

Rozvany, G. I. (2009). A critical review of established methods of structural topology optimization. Struct. Multidisc. Optim., Vol. 37, pp. 217-237.

Sigmund, O., & Petersson, J. (1998). Numerical instabilities in topology optimization: A survery on procedures dealing with checkerboards, mesh-dependencies and local minima. Structural Optimization, Vol. 16, pp. 68-75.

Silva, E., Nishiwaki, S., Fonseca, J., & Kikuchi, N. (1999). Optimization Methods Applied to Material and Flextensional Actuator Design Using the Homogenization Method. Compt. Methods Appl. Mech. Engrg., Vol. 172, pp. 241-271.

SUN Hongtu, H., MA, N., SHEN, G., & LIU, B. (2010). Application of Hot Forming High Strength Steel Parts on Car Body in Side Impact.

Suzuki, K., & Kikuchi, N. (1991). A homogenization method for shape and topology optimization. Comput. Methods Appl. Mech. Energ., Vol. 93, pp. 291-318.

Tachibana, M. e. (2002). Plastic Bolster (Radiator Core Support). Nissan Technical Review, No. 50, pp. 47–50.

Tochioka, T. e. (2002). Development of module carriers by injection molding with glass fiber reinforced polypropylene. JSAE, No. 31-02, pp. 5–8.

ULSAB organization. (1997). Data distributed by the ULSAB organization. ULSAB.

Vanderplaats, G. N. (1984). Numerical optimization techniques for enineering design with applications. McGraw-Hill.

Zoutendijk, G. (1960). Methods of Feasible Directions. Amsterdam: Elsevier.