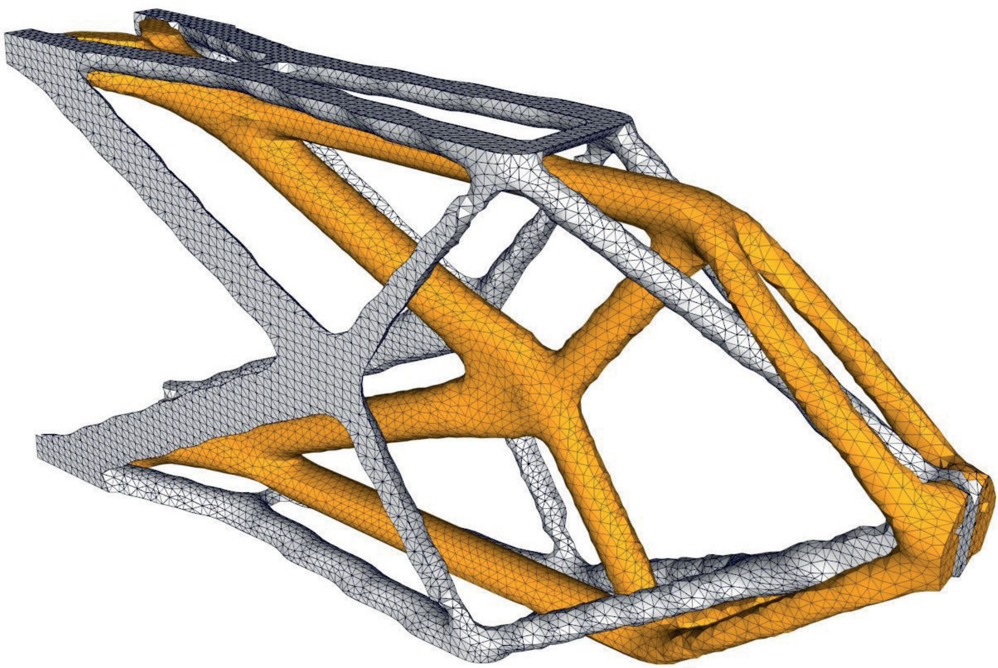
Topology optimization method for the adaptation of mechanical structures

Bergische Universität Wuppertal
Lehrstuhl für Optimierung mechanischer Strukturen

Saad Eddine Hafsa



Topology optimization method for the adaptation of mechanical structures

Thesis
to obtain a doctoral degree

in the
School of Mechanical and Safety Engineering
of the
University of Wuppertal

Submitted by
Saad Eddine Hafsa
from Tunis

Wuppertal 2020

Berichte aus dem Maschinenbau

Saad Eddine Hafsa

Topology optimization method for the adaptation of mechanical structures

Shaker Verlag
Düren 2021

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available in the Internet at http://dnb.d-nb.de.

Zugl.: Wuppertal, Univ., Diss., 2021

Printed in Germany.

ISBN 978-3-8440-8306-4
ISSN 0945-0874

Shaker Verlag GmbH • Am Langen Graben 15a • 52353 Düren
Phone: 0049/2421/99011-0 • Telefax: 0049/2421/99011-9
Internet: www.shaker.de • e-mail: info@shaker.de

Saad Eddine Hafsa

Topology optimization method for the adaptation of mechanical structures

PhD thesis, University of Wuppertal, School of Mechanical Engineering and Safety Engineering, Chair for Optimization of Mechanical Structures, december 2020

Abstract

Adaptation of structures is done when an object is used commonly in a product family with variants having different requirement levels. An example of this process is when a series vehicle is the basis for the design of a motorsport vehicle where stiffness and rigidity behavior have to be adapted to a new specific use. To do so, reinforcements are added using specific struts and framework structures.

To find the topology of these reinforcing structures, the known topology optimization methods do not deliver satisfying results because the added material is spread on the surface of the basis structure, which makes their manufacturing difficult and costly.

In this thesis, an analysis of the adaptation task from the structural point of view is made and compared to the classical structural design and optimization task from scratch. All adaptation cases are classified depending on the type of basis structure and the investigated load case. Furthermore, some benchmark problem statements to assess the performance of adaptation methods are proposed.

A new method is presented that allows to generate reinforcing structures that are producible, without significant loss in performance compared to the results obtained with the so far available methods. In order to give the user more control over the optimization outcome, several features are implemented as input parameter such as the distance between basis and added structures or the properties of the connections between them.

To validate the method, an extensive parameter study applied on several adaptation cases and on 2D and 3D models is conducted. Finally some further adaptation cases are investigated, such as when members of the basis structure are removed and sequential steps adaptations.

Keywords: Topology optimization, adaptation, reinforcement, pre-existing members, density method, geometric features, framework structures, vehicle body.

Saad Eddine Hafsa

Topologieoptimierungsmethode für die Adaption von mechanischen Strukturen

Dissertation, Bergische Universität Wuppertal,
Fakultät für Maschinenbau und Sicherheitstechnik,
Lehrstuhl für Optimierung mechanischer Strukturen, Dezember 2020

Kurzfassung

Wenn eine Komponente kommunal innerhalb einer Produktfamilie verwendet wird, obwohl unterschiedliche Anforderungen an das Gesamtsystem vorliegen, wird eine Adaption der Strukturen benötigt. Ein Beispiel hierfür ist die Anpassung eines Serienfahrzeugs als Basis der Entwicklung eines Rennsportwagens bei dem Steifigkeiten und Festigkeiten für den neuen Anwendungszweck angepasst werden müssen. Zu diesem Zweck werden Verstärkungen in Form von Streben und Fachwerkstrukturen hinzugefügt.

Die bestehenden Optimierungsmethoden zur Ermittlung der Topologien der verstärkenden Strukturen liefern nicht umsetzbare Ergebnisse. Dies liegt daran, dass das hinzugefügte Material auf die Oberfläche der Basisstruktur verteilt wird. Hierdurch wird eine Interpretation und Herstellung schwierig und teuer.

In der vorliegenden Dissertation wird die Adaptionsaufgabe aus Gesichtspunkten der Strukturauslegung untersucht und mit klassischen Strukturoptimierungsproblemen verglichen. Alle Adaptionsfälle sind klassifiziert in Abhängigkeit von der Art der Basisstruktur und dem untersuchten Lastfall. Außerdem werden Benchmark-Modelle, um die Leistung von Adaptionsmethoden zu prüfen, vorgeschlagen.

Eine neue Methode wird vorgestellt, die es ermöglicht herstellbare, verstärkende Strukturen zu generieren ohne Verlust an Steifigkeitspotenzial im Vergleich zu vorhandenen Methoden. Um den Anwender mehr Einfluss auf die generierten Topologien zu geben, werden mehrere Merkmale als Eingabeparameter implementiert. Hierzu zählen beispielsweise der Abstand zwischen Basis und verstärkenden Strukturen sowie die Eigenschaften der Verbindungselemente.

Um die Methode zu validieren, wird eine umfangreiche Parameteranalyse durchgeführt und in mehrere Adaptionsfälle auf 2D und 3D Modelle angewendet. Abschließend werden weitere Adaptions-Problemstellungen untersucht. Hierzu gehört der Fall, bei dem Teile der Basisstruktur entfernt werden. Ein weiteres Beispiel ist die Durchführung einer Adaption in sequentiellen Schritten.

Stichworte: Topologieoptimierung, Adaptation, Verstärkung, Basisstruktur, Dichtemethode, geometrische Eigenschaften, Fachwerkstrukturen, Karosserie.

Acknowledgments

This thesis was written during my employment as PhD Student at the BMW Group in the department for the design of motorsport vehicles. I would like to thank here everyone who contributed to the success of this project.

First of all I would like to thank my doctoral thesis supervisor Prof. Dr.-Ing. Axel Schumacher who gave me throughout the project the right advice to achieve advances in this research field and successfully find a solution to this topic. Also I address my thanks to all the actual and former PhD students of the chair who were a precious source of inspiration and improvement ideas.

To Prof. Dr. Wolfgang Achtziger from the Friedrich-Alexander University Erlangen-Nuremberg I would like to address my sincere gratitude for accepting to be the second reviewer for the assessment of this thesis.

My group leader at BMW Group Olivier Jansonnie gave me the necessary space to focus on my thesis, by understanding the requirements of a research activity inside an industrial environment. He was also a great help by challenging me on the benefits of my results for practical applications.

My supervisor Mohammed Ruhaidi gave me all the necessary tools to conduct my research in the best conditions and gave me important insights in the structural computation challenges in motorsport environment.

I am grateful for the financial support from the BMW Group and for their ProMotion program through which I met several other PhD students in diverse research fields, which lead to interesting discussions and exchanges. Just to name a few I thank Dr.-Ing. Mariam Jaber and Dr.-Ing. Alaa Mourad for their continuous support.

A special thanks goes to Javed Butt and Jens Trilling wo helped me through their internships and thesis works with great commitment and essential contributions for the success of this work.

The final thanks goes to my family and friends who supported me during this journey.

Wuppertal in december 2020 Saad Eddine Hafsa

Contents