

# **SpringerBriefs in Applied Sciences and Technology**

## **Series editor**

Janusz Kacprzyk, Polish Academy of Sciences, Systems Research Institute,  
Warsaw, Poland

SpringerBriefs present concise summaries of cutting-edge research and practical applications across a wide spectrum of fields. Featuring compact volumes of 50–125 pages, the series covers a range of content from professional to academic.

Typical publications can be:

- A timely report of state-of-the art methods
- An introduction to or a manual for the application of mathematical or computer techniques
- A bridge between new research results, as published in journal articles
- A snapshot of a hot or emerging topic
- An in-depth case study
- A presentation of core concepts that students must understand in order to make independent contributions

SpringerBriefs are characterized by fast, global electronic dissemination, standard publishing contracts, standardized manuscript preparation and formatting guidelines, and expedited production schedules.

On the one hand, **SpringerBriefs in Applied Sciences and Technology** are devoted to the publication of fundamentals and applications within the different classical engineering disciplines as well as in interdisciplinary fields that recently emerged between these areas. On the other hand, as the boundary separating fundamental research and applied technology is more and more dissolving, this series is particularly open to trans-disciplinary topics between fundamental science and engineering.

Indexed by EI-Compendex and Springerlink.

More information about this series at <http://www.springer.com/series/8884>

Jan-Hendrik Wehner · Dominic Jekel  
Rubens Sampaio · Peter Hagedorn

# Damping Optimization in Simplified and Realistic Disc Brakes

 Springer

Jan-Hendrik Wehner  
Weinheim  
Germany

Dominic Jekel  
Dynamics and Vibrations Group  
Technical University of Darmstadt  
Darmstadt, Hessen  
Germany

Rubens Sampaio  
Department of Mechanical Engineering  
Pontifical Catholic University of Rio  
Rio de Janeiro  
Brazil

Peter Hagedorn  
Dynamics and Vibration Group  
Technical University of Darmstadt  
Darmstadt, Hessen  
Germany

ISSN 2191-530X                      ISSN 2191-5318 (electronic)  
SpringerBriefs in Applied Sciences and Technology  
ISBN 978-3-319-62712-0            ISBN 978-3-319-62713-7 (eBook)  
DOI 10.1007/978-3-319-62713-7

Library of Congress Control Number: 2017946042

© The Author(s) 2018

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

The publisher, the authors and the editors are safe to assume that the advice and information in this book are believed to be true and accurate at the date of publication. Neither the publisher nor the authors or the editors give a warranty, express or implied, with respect to the material contained herein or for any errors or omissions that may have been made. The publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Printed on acid-free paper

This Springer imprint is published by Springer Nature  
The registered company is Springer International Publishing AG  
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

# **Acknowledgements**

The support through DFG HA 1060/55-1, Ingenieurgesellschaft für technische Software mbH (INTES), and Dr.-Ing. h.c. F. Porsche AG is gratefully acknowledged.

# Contents

<b>1</b>	<b>Introduction</b> . . . . .	1
	References. . . . .	2
<b>2</b>	<b>Theoretical Background</b> . . . . .	3
2.1	Linearization of Nonlinear Equations of Motion. . . . .	3
2.2	Time-Invariant MDGKN-Systems. . . . .	4
2.3	First-Order Systems . . . . .	5
2.4	Time-Periodic Systems and FLOQUET Theory . . . . .	5
2.5	Optimization of Damping. . . . .	7
	2.5.1 Time-Invariant Systems. . . . .	7
	2.5.2 Time-Periodic Systems . . . . .	7
2.6	Linear Damping Models. . . . .	8
	2.6.1 COULOMB Damping . . . . .	9
	2.6.2 Viscous Damping . . . . .	10
	2.6.3 Structural Damping. . . . .	10
2.7	Modal Reduction . . . . .	12
2.8	Brake Squeal . . . . .	13
	References. . . . .	13
<b>3</b>	<b>Optimization of a Minimal Model of Disc Brake</b> . . . . .	17
3.1	Equations of Motion. . . . .	17
3.2	Optimization Technique . . . . .	19
3.3	Optimization Results. . . . .	20
	3.3.1 Time-Invariant Model . . . . .	20
	3.3.2 Time-Periodic Model . . . . .	24
	3.3.3 Discussion. . . . .	26
3.4	Traps and Shortcomings of CEA . . . . .	26
	References. . . . .	30

- 4 Optimization of Finite Element Models of Disc Brakes . . . . . 31**
- 4.1 Theoretical Background . . . . . 31
- 4.2 Low-Degree-of-Freedom Model . . . . . 36
  - 4.2.1 Optimization Results . . . . . 36
  - 4.2.2 Discussion . . . . . 39
- 4.3 High-Dimensional Industrial Model . . . . . 40
  - 4.3.1 Optimization Results . . . . . 42
  - 4.3.2 Discussion . . . . . 47
- References. . . . . 47
- 5 Conclusion . . . . . 49**