# Handbook of Railway Vehicle Dynamics

in numerical simulations in the electromagnetic and mechanical domains. His research field goes from the modelling of linear induction motors to railways dynamics. He is the author of several innovations in the modelling of the wheel rail contact and the multibody formalism, implemented in the VOCO code.

**Hugues Chollet** is Researcher at INRETS (FRANCE). He graduated from UTC in 1984 and obtained a PhD in 1991 at Université Pierre et Marie Curie, PARIS 6, on the experimental validation of Kalker's theory for the use in wheel rail contact. He carries out research and consultancy work on guided transportation systems, dealing with wheel rail contact fatigue, derailment situations, instabilities, vibration and comfort problems. He is a referee and board member of several journals and elected member at the IAVSD board.

**Ulf Olofsson** is a senior lecturer and reader in tribology at the Royal Institute of Technology in Stockholm Sweden where he lectures in tribology and machine elements. Before joining the Royal Institute of Technology he worked at the Swedish National Testing and Research Institute with tribological material and component testing and obtained his Lic Eng from Chalmers University of Technology in 1994 and a Ph.D. from the Royal Institute of Technology in 1996. Dr. Olofsson has ten years research experience of the tribology of the wheel–rail contact and supervises postgraduate students and carries out research and consultancy work on government and industry-funded projects. His main research interests include contact mechanics, wear and friction simulation of the wheel–rail contact, wheel and rail wear mapping, and characterisation of the wear mechanisms in the wheel–rail interface.

**Roger Lewis** is a lecturer in the Department of Mechanical Engineering at the University of Sheffield where he teaches design and tribology. He received his Ph.D. in 2000 from the same department before joining the academic staff in 2002. His research has two main areas of focus. The first is in solving industrial wear problems and he is currently working on a number of government and industry-funded projects involving automotive and railway applications. His other area of work is in developing and applying a novel ultrasonic technique for characterising machine element contacts. He has worked on a number of projects related to the wheel–rail interface including the development of a CAE tool for wheel wear prediction, wheel and rail wear mapping, a study of wheel–rail isolation due to track contamination, and characterisation of the wheel–rail interface.

**Tore Dahlberg** is Professor of Solid Mechanics at Linköping University in Linköping, Sweden. He graduated from the School of Mechanical Engineering at Chalmers University of Technology (Gothenburg, Sweden) in 1970 and worked for two years in Burundi, Africa. He gained his Ph.D. at Chalmers in 1979, was appointed "Docent" (associate professor) in 1981, and in 1997 he transferred to Linköping University. Primarily, Professor Dahlberg's research dealt with dynamics of road vehicles, especially random vibration of road vehicles, and dynamics in general. Since the 1980s, his research mainly concerns the dynamic interaction between a train and the track and in recent years focus has been on track dynamics and track deterioration. Professor Dahlberg has published some 30 papers in refereed international journals and he is the author of two textbooks: one in strength of materials and one in fracture mechanics and fatigue. Also, other papers, reports, educational materials, and some popular articles on railway track dynamics have been written by him.

**David M. Johnson** is CEO of Laser Rail Ltd, a technology company specialising in the analysis of the rail vehicle-structure interface. He has been a major contributor to the development of analytical techniques for gauging from empirical methodologies, and in doing so has enabled the running of modern, larger rolling stock on restrictive infrastructure. Mr. Johnson has 28 years of experience in the railway industry, half of which was spent as an engineer with British Rail Research. He has been coauthor of a number of gauging standards and guidance texts, is the

# Handbook of Railway Vehicle Dynamics

Edited by Simon Iwnicki



CRC is an imprint of the Taylor & Francis Group, an informa business

Front cover illustration: A multibody passenger vehicle model developed by Yann Bezin using MSC.Adams and VI-Rail.

Published in 2006 by CRC Press Taylor & Francis Group 6000 Broken Sound Parkway NW, Suite 300 Boca Raton, FL 33487-2742

© 2006 by Taylor & Francis Group, LLC CRC Press is an imprint of Taylor & Francis Group

No claim to original U.S. Government works Printed in the United States of America on acid-free paper 10 9 8 7 6 5 4 3 2 1

International Standard Book Number-10: 0-8493-3321-0 (Hardcover) International Standard Book Number-13: 978-0-8493-3321-7 (Hardcover) Library of Congress Card Number 2006002255

This book contains information obtained from authentic and highly regarded sources. Reprinted material is quoted with permission, and sources are indicated. A wide variety of references are listed. Reasonable efforts have been made to publish reliable data and information, but the author and the publisher cannot assume responsibility for the validity of all materials or for the consequences of their use.

No part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (http://www.copyright.com/) or contact the Copyright Clearance Center, Inc. (CCC) 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

#### Library of Congress Cataloging-in-Publication Data

Handbook of railway vehicle dynamics / Simon Iwnicki.
p. cm.
Includes bibliographical references and index.
ISBN-13: 978-0-8493-3321-7
1. Railroads--Cars--Dynamics--Handbooks, manuals, etc. I. Iwnicki, S. (Simon), 1962-

TF550.H37 2006 625.2--dc22

2006002255



Visit the Taylor & Francis Web site at http://www.taylorandfrancis.com

and the CRC Press Web site at http://www.crcpress.com

### Contributors

**Simon Iwnicki** is a principal lecturer at Manchester Metropolitan University where he teaches applied mechanics and dynamics. Dr. Iwnicki has 15 years of railway vehicle computer modelling experience and has presented papers to international conferences and lectured widely on vehicle–track interaction. He is the editor of the *Journal of Rail and Rapid Transit* and the co-editor (responsible for railway matters) of the international journal *Vehicle System Dynamics*. He is the head of the Rail Technology Unit, a research and consultancy group based in the Department of Engineering and Technology. The unit specialises in the use of computer simulation tools for a variety of railway applications and carries out research and consultancy work on government and industry-funded projects. Dr. Iwnicki is a member of the technical advisory group of the United Kingdom Vehicle/Track System Interface Committee.

**A. H. Wickens** is currently Visiting Industrial Professor at the Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University, where his present research interest is in the active guidance and dynamic stability of unconventional railway vehicles. Educated as an aeronautical engineer, he joined British Railways Research in 1962 to carry out research into the dynamics of railway vehicles. He was Director of Research 1971–1983 and Director of Engineering Development and Research 1983–1989. From 1987 to 1990 Professor Wickens was Chairman of the Office for Research and Experiments of the International Union of Railways in Utrecht. He was Professor of Dynamics in the Department of Mechanical Engineering at Loughborough University 1989–1992 and is an honorary member of the Association for Vehicle System Dynamics.

**Anna Orlova** is the Head of the Dynamics and Structural Mechanics Department at the Scientific Research Centre "Vagony" based at the Petersburg State Transport University in St Petersburg, Russia. The department carries out simulation and research testing in the field of railway vehicle dynamics. Dr. Orlova's special interests include optimisation of running gear parameters for dynamic performance, evaluation of design schemes, and the development of simulation models and testing methods. Dr. Orlova is a supervisor of diploma students at Petersburg State Transport University and the author of several textbooks on bogie design and multibody dynamics simulation.

**Yuri Boronenko** is Professor and Head of the Department of Railway Cars at the Petersburg State Transport University in St Petersburg, Russia. Professor Boronenko is also the Director of the Scientific Research Centre "Vagony" — the independent institution at the Federal Railway Agency of Russia. The centre is involved in many practical fields such as monitoring the fleet of freight wagons in Russia, evaluation of the technical condition of railway vehicles, design of new and modification of existing railcars, and implementation of repair technologies as well as in research and consultancy projects for RZD and industry. Vagony is also a certified testing centre on the Russian Railway Register. Professor Boronenko's special interests include motion of liquids in railway wagons and vehicle dynamics. For his theoretical and practical contribution in developing railway vehicles Professor Boronenko was made a member of the Transport Academy of Russia.

**Jean-Bernard Ayasse** is Research Director at INRETS (FRANCE). Before joining INRETS he worked at the CEA, Comissariat à l'Energie Atomique, and obtained his PhD from the University of Grenoble in 1970, and a State Thesis in 1977 in solid state physics. He is a specialist

technical advisor to the Vehicle/Structures Systems Interface Committee, and is a visiting reader in mechanical engineering at Imperial College, London.

**Huimin Wu** is a principal investigator at Transportation Technology Center, Inc. (TTCI) in Pueblo, Colorado, U.S.A. Dr. Wu has more than 14 years of experience in the simulation, analysis, and testing of railway vehicles. Her research carries over into areas including vehicle dynamics, vehicle-track interaction, wheel flange climb derailment criteria, computation methodology of studying wheel-rail contact, NUCARS development, wheel-rail profile design, and rail grinding. She has presented papers at international conferences on vehicle-track interaction and published a number of reports on consultancy work carried out for the railways.

**Nicholas Wilson** (BSME, Cornell University, 1980) is a scientist at the Transportation Technology Center, Inc. (TTCI) in Pueblo, Colorado, U.S.A., specialising in rail vehicle dynamics and wheel-rail interaction. He leads the team of engineers developing TTCI's NUCARS multibody vehicle-track dynamic interaction software. Recently, he has also been working on flange climb derailment research, derailment investigations of transit vehicles, wheel-rail wear, and RCF studies. He has also been working on developing rail vehicle dynamic performance specifications for, and analysing performance of trains to carry high-level radioactive material.

**Colin Cole** is a senior lecturer at Central Queensland University where he teaches fluid mechanics and system dynamics. He is also the Deputy Director and Mechanical Group Leader at the Centre for Railway Engineering (CRE), rail research and consultancy group based in the faculty of engineering. His involvement in the rail industry dates back to 1984, including six years experience working in mechanised track maintenance at Queensland Railways. Since 1994 he has conducted a range of rail research and consultancy projects related to field testing of trains, simulation, and development of intelligent systems. He has authored or coauthored 21 technical papers, developed two patents and contributed to numerous commercial research and consulting reports. Dr. Cole is a member of the Engineers Australia and a member of the Queensland Chapter Committee of the Railway Technical Society of Australia.

**David Thompson** is Professor of Railway Noise and Vibration at the Institute of Sound and Vibration Research (ISVR), University of Southampton. Before joining the ISVR in 1996 he worked at British Rail Research in Derby, United Kingdom and TNO Institute of Applied Physics in Delft, the Netherlands and obtained his Ph.D. from the ISVR in 1990. He has written 65 papers in refereed journals and 120 other papers. He is the main author of the TWINS software for railway rolling noise. His research interests include a wide range of aspects of railway noise and vibration as well as noise control, vibroacoustics, structural vibration, modelling rubber, experimental methods for transfer path analysis, and inverse force determination. He teaches undergraduate and masters level courses and is programme organiser for the M.Sc. in sound and vibration.

**Chris Jones** is Reader in Railway Noise and Vibration at the Institute of Sound and Vibration Research (ISVR) at Southampton University. He joined the ISVR from British Rail Research in 1997 where his main interests were in the development and application of numerical models for noise and ground vibration from trains. He continues to work for the railway industry through research and consultancy. He has worked for many railway and tramway projects in the United Kingdom and internationally as well as for track and rolling stock suppliers to develop noise control measures. Dr. Jones teaches numerical methods in acoustics on the bachelors and masters degree programmes at the ISVR and has authored over 80 publications about 30 of which are academic journal papers.

**R. M. Goodall** is Professor of Control Systems Engineering in the Electronic and Electrical Engineering Department at Loughborough University in the United Kingdom. He holds B.A. and

M.A. degrees in engineering from the University of Cambridge, and a Ph.D. degree from Loughborough University. He worked in one of the United Kingdom's GEC companies immediately after graduation before moving to British Rail's Research Division in 1970. He transferred to Loughborough University in 1982 and became a full professor in 1994. His research is concerned with a variety of practical applications of advanced control for high performance electromechanical systems, with a particular specialism related to the railway and aircraft industries. Professor Goodall is a fellow of the IEE and the IMechE in the United Kingdom.

**T. X. Mei** from the University of Leeds is a senior lecturer in control engineering where he leads a research group at the School of Electronic and Electrical Engineering, carrying out leading-edge research in the area of control and systems study for railway vehicles. Dr. Mei has a strong background in railway engineering and substantial expertise in vehicle dynamics and traction control. He has given invited research seminars at an international level and published many papers in leading academic journals and international conferences which explore the application of advanced control techniques and the use of active components. Dr. Mei is one of the most active researchers worldwide in the latest fundamental research into active steering and system integration for railway vehicles, and has made significant contributions to several leading-edge research projects in the field. His educational background includes B.Sc. (1982, Shanghai Tiedao), M.Sc. (1985, Shanghai Tiedao), M.Sc. (1991, Manchester) and Ph.D. (1994, Loughborough).

**Oldrich Polach** is Chief Engineer, Dynamics, at Bombardier Transportation, Winterthur, Switzerland, responsible for sites in Business Unit Bogies Europe. Before joining the railway industry in 1993 he was a research worker and reader at the University of Transport and Communication in Žilina, Czechoslovakia, where he finished his doctoral thesis and obtained his postdoctoral lecture qualification. He teaches railway vehicle dynamics at the ETH Swiss Federal Institute of Technology Zürich and at the Technical University in Berlin. He is a member of the editorial boards of the international journals *Vehicle System Dynamics*, the *International Journal of Vehicle Systems Modelling and Testing*, and the European Railway Review, and a member of the working group "Interaction Vehicle–Track" of the European Committee for Standardisation CEN TC 256. His research interests include vehicle dynamics and contact between wheel and rail. His publication activity was awarded the PE Publishing W. A. Agnew/C. N. Goodall Award and the prestigious George Stephenson Prize in 2002.

**Mats Berg** is Professor and Head of Railway Technology at the Royal Institute of Technology (KTH) in Stockholm. Before joining KTH in 1993 he worked at ABB Traction in Västerås, University of California at Berkeley, and obtained his Ph.D. from Lund Institute of Technology in 1987. His main research field is vehicle–track interaction with emphasis on the aspects of structural dynamics, suspension dynamics, track dynamics, and wheel–rail wear. Professor Berg has authored many papers and reports in this field and advised several Ph.D. students. He teaches courses on rail vehicle dynamics and general railway engineering in degree programmes as well as for practising engineers of the railway sector (both in Sweden and internationally).

**Julian Stow** is a research fellow at the Rail Technology Unit (RTU) at Manchester Metropolitan University (MMU). He is a specialist in railway vehicle dynamics and wheel-rail interface engineering. His main area of expertise is in the field of vehicle simulation, safety and design and he has a wide knowledge of testing and instrumentation techniques required to support this work. He has been involved in investigations of rail rolling contact fatigue and a broad range of wheel-rail system problems. He regularly presents work at industry conferences and has organised two conferences on the theme of "railway freight vehicle design". Prior to joining the RTU, he worked in the automotive industry, gaining experience in testing, type approval, and suspension design for commercial vehicles.

**Evert Andersson** is Professor of Railway Technology at the Royal Institute of Technology (KTH) in Stockholm. He started the Division of Railway Technology at KTH in 1987. He also took the initiative of the Railway Group of KTH, a cross-disciplinary centre for research and education in railway engineering. Earlier he was also Chief Mechanical Systems Engineer at ABB Traction (now Bombardier Transportation) in Västerås, Sweden, where he was one of the lead engineers in the development of the high-speed train X2000. He is also an elected member of the Royal Swedish Academy of Engineering Sciences. His main research fields are rail vehicles, vehicle–track interaction and railway energy consumption. Professor Andersson is the author of a vast number of scientific papers and conference contributions in these fields. He also teaches courses on the above topics, as well as on railway engineering in general, and has supervised about ten Ph.D. students for a Ph.D. or licentiate degree.

Weihua Zhang is a professor at Southwest Jiaotong University in China. He is the leader of the Traction Power State-Key Laboratory. He holds an M.A. degree in engineering dynamics and a Ph.D. in vehicle engineering from Southwest Jiaotong University (awarded in 1989 and 1996). He teaches vehicle dynamic simulation for graduate students and virtual prototyping for undergraduate students. His research is concerned with railway vehicle dynamic simulation using computers and test rigs including a full-scale roller rig. In recent years he has worked on a high-speed train and tilting train for MOR in China.

**Huanyun Dai** is Professor of Vehicle Engineering at the Traction Power State-Key Laboratory, Southwest Jiaotong University, China. He gained M.A. and Ph.D. degrees in vehicle engineering from Southwest Jiaotong University in 1990 and 1999. He teaches control engineering to postgraduate students. His research is concerned with active suspensions, structural vibration, and roller rig testing for a variety of railway vehicle applications.

**Zhiyun Shen** is a professor at the Traction Power State-Key Laboratory of Southwest Jiaotong University. Professor Shen is an academician of the Academy of Science and the Academy of Engineering of China. He holds a B.A. degree in vehicle engineering from Tangshan Railway University of China, and a Ph.D. degree from Petersburg University of Means of Communication in the former Soviet Union. He has a long experience of teaching and researching and his main research interest has been in dynamics and wheel-rail interactions of vehicle systems.

**Jing Zeng** is a professor at the Traction Power State-Key Laboratory, Southwest Jiaotong University, China. He received MA and PhD degrees in vehicle engineering from Southwest Jiaotong University in 1987 and 1991. He teaches vehicle engineering and vehicle nonlinear system dynamics for undergraduate students and graduate students. He is the vice-director of the laboratory and the leader of research and consultancy group on vehicle dynamics and strength. His research is concerned with the use of computer simulation and roller rig testing for a variety of railway vehicle applications. In recent years he has carried out research and consultancy work on many government and industry-funded projects.

**P. D. Allen** is a research fellow working at Manchester Metropolitan University (MMU), within the Rail Technology Unit. He has a first degree in mechanical engineering and a Ph.D. gained through studies of wheel-rail interaction, particularly the details of errors inherent in scale testing of vehicles on roller rigs. He teaches on postgraduate courses in railway engineering and also carries out varied research and consultancy work under government and industrially funded projects. Dr. Allen is currently involved in working with light rail operators in the United Kingdom, specialising in optimising the wheel-rail interface, together with research work including the integrated modelling of wheel squeal and vehicle dynamics, and neural network prediction of derailment.

### Table of Contents

Chapter 1	Introduction
Simon Iwnic	ki
Chapter 2	A History of Railway Vehicle Dynamics
A. H. Wicke	ns
Chapter 3	The Anatomy of Railway Vehicle Running Gear
Anna Orlova	a and Yuri Boronenko
Chapter 4	Wheel-Rail Contact
Jean-Bernar	d Ayasse and Hugues Chollet
Chapter 5	Tribology of the Wheel-Rail Contact
Ulf Olofssor	a and Roger Lewis
Chapter 6	Track Issues
Tore Dahlbe	erg
Chapter 7	Gauging Issues
David M. Jo	hnson
Chapter 8	Railway Vehicle Derailment and Prevention
Huimin Wu	and Nicholas Wilson
Chapter 9	Longitudinal Train Dynamics
Colin Cole	
Chapter 10	Noise and Vibration from Railway Vehicles
David Thom	pson and Chris Jones
Chapter 11	Active Suspensions
R. M. Goodd	all and T. X. Mei
Chapter 12	Simulation
Oldrich Pol	ach, Mats Berg, and Simon Iwnicki

Chapter 13	Field Testing and Instrumentation of Railway Vehicles	423	
Julian Stow and Evert Andersson			
•	Roller Rigs	457	
	Scale Testing	507	
P. D. Allen	Scale resting	507	