STAGE 6

TRIENNIAL REPORT
1 July 2009–30 June 2012

REVIEW
1 July 1995–30 June 2009

PLANS
1 July 2012–30 June 2015

CHARMEC

Chalmers Railway Mechanics – a NUTEK/VINNOVA Competence Centre
Chalmers University of Technology

FOREWORD

This is a report on the organization, operation and financing of Stage 6 (1 July 2009 – 30 June 2012) of the Swedish National Competence Centre CHARMEC, which originated from a NUTEK/VINNOVA government grant for the period 1995-2005. Summaries of the research conducted at the Centre are presented. A review of Stages 1, 2, 3, 4 and 5 and a look forward at Stage 7 are also included.

The fold-out on pages 124-126 contains an overview of all CHARMEC projects (now 101) that are either ongoing or have been implemented since the Centre started.

Professor Emeritus Bengt Åkesson has assisted with the compilation and editing of this Triennial Report.

Gothenburg in September 2012

ROGER LUNDÉN
Director of CHARMEC

William Chalmers (1748-1811) from Gothenburg, Director of the Swedish East India Company, bequeathed a large sum of money to the start in 1829 of an industrial school that later became the Chalmers University of Technology

Front cover: Photoelastic experiment illustrating stress fields arising during two-point contact between wheel and rail

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REFLECTIONS

from the Director

In its 2011 White Paper on Transport, the European Commission states that it is necessary to drastically reduce greenhouse gas emissions without curbing the mobility of people and goods, and notes the need for high-capacity, cost-efficient, punctual and environmentally friendly railway systems that can handle a greater proportion of the transportation volumes. This will raise the bar for the railway sector, as its systems are an intricate web of interacting technologies, operations, companies and interests, where modifications in one area may lead to unintended consequences in another. There is a need for everyone involved to have a high level of competence, as we work to increase capacity, whilst keeping costs, delays, safety etc at acceptable levels.

Railway mechanics will remain a cornerstone in any reliable railway system. Augmented demands on performance directly affect the mechanical loading of vehicles and infrastructure and, as is often the case when a system is becoming increasingly optimized, the margin for errors will shrink. Small deviations in design or maintenance may then cause large-scale "epidemics" of component damage, or even the nationwide collapse of a railway system. The need to understand mechanical phenomena and the expertise required when predicting and mitigating negative incidents have never been greater.

On the following pages, we provide an overview of our research, the overall aim of which is to understand and predict loading, deformation, vibration, noise-emission, deterioration etc of railway components and systems. Railway mechanics is, however, not an island but requires close co-operation with other disciplines, such as economy and logistics, not to mention industrial engineering which is the area where our research results are being implemented. These links always exist, but they are especially noticeable in the European projects presented on pages 83-91.

Finally, the ultimate fate of CHARMEC is in the hands of the individuals involved in the centre's research activities: the qualified staff of our industrial partners, our dedicated doctoral students and senior researchers, and the knowledgeable colleagues from all over the world with whom we co-operate. Thanks to all of them, we know that the challenges currently facing the railway systems will be met.

Main entrance to Chalmers University of Technology with the Student Union building on the right

EXECUTIVE SUMMARY

The Competence Centre CHAlmers Railway MEChanics, abbreviated CHARMEC, was established in July 1995 at Chalmers University of Technology in Gothenburg, Sweden. It had its origin in a small-scale railway mechanics research programme which was set up in 1987, at the Department of Solid Mechanics (since 2005 part of the Department of Applied Mechanics) in collaboration with the company Sura Traction (now Lucchini Sweden). A key factor to the success of CHARMEC has been the long-term commitment of Banverket (now Trafikverket, the Swedish Transport Administration) and the Centre's industrial partners. Four of the current eleven partners (including Lucchini) have been involved since 1995, and another four have been involved for nine years or more. Two members have served on the CHARMEC Board since 1995 and will continue to do so during Stage 7 (1 July 2012 – 30 June 2015). Another key factor is the core group of committed CHARMEC researchers at Chalmers University of Technology who have served the Centre for a very long time, and are still actively involved. Some of them have worked for CHARMEC since the start in 1995, or even from the start of the railway-related activities in 1987.

The Swedish Governmental Agency for Innovation Systems (VINNOVA) organized a third international evaluation of CHARMEC at the end of the Centre's Stage 3. Conclusions from the evaluators were: *CHARMEC has established itself as an internationally recognized multidisciplinary Centre of Excellence in railway mechanics.* No such evaluation has taken place since 2003. However, in 2011 VINNOVA initiated an investigation into the impact CHARMEC has had on the companies that have participated/participate in different research centres. CHARMEC and several of our partners have contributed to this study.

The annual budget for the three years of Stage 6 (1 July 2009 – 30 June 2012) has been MSEK 22.9 (about MEUR 2.7), see page 120. Three parties have provided funding: Chalmers University of Technology, Banverket/Trafikverket, and an Industrial Interests Group comprising ten partners. In total, 26 ordinary research projects, 3 EU projects and 9 development projects were carried out within the six programme areas during Stage 6,

- Interaction of Train and Track
- Vibrations and Noise
- Materials and Maintenance
- Systems for Monitoring and Operation
- Parallel EU Projects
- Parallel Special Projects

At Chalmers, 38 people (project leaders, academic supervisors, doctoral students and senior researchers) from 4 departments (out of a total of 17 at Chalmers, see page 127) have been involved. They published 95 scientific papers in international journals and conference proceedings during Stage 6 (including those in print). Eleven Licentiate degrees and four PhD degrees were conferred during Stage 6. A total of 45 Licentiate degrees and 30 PhD degrees in railway mechanics have been awarded to date (June 2012) at Chalmers, see page 106. Around 60 partners (industries, universities, institutes, public agencies, consultancies) from 12 countries have been involved in our European projects during Stage 6.

CHARMEC endeavours to combine academic excellence and industrial relevance while generating first-rate research and skilled PhDs. Our work includes mathematical modelling, numerical studies, laboratory experiments and full-scale field measurements. We have worked closely with Banverket/Trafikverket and the Industrial Interests Group. Knowledge has been transferred in both directions through advisory groups and industrial site visits, regular seminars and brain-storming meetings as well as co-authored journal papers, co-ordinated conference participation and joint field experiment campaigns. The inertia dynamometer for braking experiments at the Lucchini Sweden plant site at Surahammar has been at our disposal. Activities will continue during Stage 7.

Funding (MSEK) of CHARMEC during Stages 1 to 4 excluding EU projects and during Stages 5, 6 and 7 including EU projects

Stage	At start of Stage			At end of Stage		
	Cash	In-kind	Total	Cash	In-kind	Total
1	11.7	8.8	20.5	11.7	8.8	20.5
2	31.6	25.0	56.6	34.6	25.0	59.6
3	36.4	26.2	62.6	43.9	25.7	69.6
4	34.8	28.4	63.2	45.9	27.5	73.4
5	48.5	21.6	70.1	52.4	21.6	74.0
6	43.4	17.2	60.6	51.4	17.2	68.6
7	52.8*	16.6*	69.4*			

Note that Stage 1 only lasted two years whereas the following Stages are for three years

The approximate exchange rate (September 2012) is 1 MSEK = 0.12 MEUR

* After Board Meeting on 13 September 2012

INTRODUCTION

CHARMEC is an acronym for *CHA*lmers *R*ailway *MEC*hanics. This Centre of Excellence, or Competence Centre, was established at Chalmers University of Technology in 1995. A formal agreement was reached at the Swedish National Board for Industrial and Technical Development (NUTEK) in Stockholm on 7 July 1995. The total funding for Stage 1 (1 July 1995 – 30 June 1997) with a total of MSEK 20.5 was agreed on by NUTEK, the University and the four partners Banverket, Abetong Teknik, Adtranz Wheelset (now Lucchini Sweden) and SJ Machine Division. Research in railway mechanics began on a small scale at Chalmers Solid Mechanics in 1987, when a first bilateral contract was signed between Bengt Åkesson of that department and Åke Hassellöf of Sura Traction (later ABB Sura Traction and Adtranz Wheelset, and now Lucchini Sweden).

CHARMEC's Stage 2 (1 July 1997 – 30 June 2000) was agreed on at a meeting in Stockholm on 10 October 1997. Cardo Rail (later SAB WABCO Group, now Faiveley Transport), Duroc Rail and Inexa Profil then joined as new industrial partners.

An agreement for CHARMEC's Stage 3 (1 July 2000 – 30 June 2003) was reached at NUTEK's office in Stockholm on 22 June 2000. In addition to the six previous members, a new member, Adtranz Sweden (now Bombardier Transportation Sweden), joined the Industrial Interests Group. During Stage 3, Inexa Profil went into receivership and left CHARMEC. As of 1 January 2001, NUTEK's responsibility for CHARMEC was taken over by the Swedish Governmental Agency for Innovation Systems (VINNOVA).

An agreement for CHARMEC's Stage 4 (1 July 2003 – 30 June 2006) was reached at VINNOVA's office in Stockholm on 19 June 2003. Green Cargo AB (a Swedish freight operator), SL Technology (a division of AB Storstockholms Lokaltrafik / Stockholm Urban Transit Administration) and voestalpine Bahnsysteme GmbH & CoKG (Austrian rail and switch manufacturer) joined as new industrial partners. All three had become involved during Stage 3. VINNOVA's MSEK 6.0 per annum was only paid during the first two years of Stage 4. TrainTech Engineering Sweden AB (now Interfleet Technology AB) replaced SJ Machine Division.

The Principal Agreement for CHARMEC's Stage 5 (1 July 2006 – 30 June 2009) followed VINNOVA's Principal Agreement for the Centre's Stage 4. However, Banverket was directly included in the agreement and also assigned part of the administrative role that was previously filled by VINNOVA. Otherwise, the rights and obligations of the three parties (Chalmers University of Technology, Banverket and the Industrial Interests Group) were the same as in the Principal Agreement for Stage 4. In addition to the previous nine members at the end of Stage 4, SJ AB and SweMaint AB joined the Industrial Interests Group during Stage 5. One member, Duroc Rail, left CHARMEC at the end of Stage 4.

The Principal Agreements for Stages 5 and 6 were constructed in the same form as that for Stage 4 and involved the same members of the Industrial Interests Group. Jan-Eric Sundgren, President of Chalmers University of Technology, and Karin Markides, new President from 1 July 2006, signed the contracts for Stage 5 on 19 June and 19 September 2006, respectively. President Karin Markides signed the eleven contracts for Stage 6 on 9 June 2009. As of 1 April 2010, Banverket was merged into the new governmental authority Trafikverket .

A brief outline of CHARMEC's Stage 7 (1 July 2012 – 30 June 2015) is presented on page 123. The volume of CHARMEC's activities since the start is set out in the table on page 6.

The three parties to the agreement on CHARMEC's Stage 6 were:

Chalmers University of Technology

Banverket / Trafikverket – now the Swedish Transport Administration (being responsible for the construction, operation and maintenance of all state owned roads and railways, and also for the development of long-term plans for the transport system on road, railway, sea and flight) with its administrative centre in Borlänge

The Industrial Interests Group

- *Abetong* – a *HeidelbergCement Group* company and concrete sleeper manufacturer with headquarters in Växjö
- *Bombardier Transportation* – an international train manufacturer with Swedish headquarters in Västerås
- *Faiveley Transport* – an international manufacturer of braking systems with Swedish headquarters in Landskrona
- *Green Cargo* – a railway freight operator with headquarters in Stockholm/Solna
- *Interfleet Technology* – an international consulting company with Swedish headquarters in Stockholm/Solna
- *Lucchini Sweden* – a wheelset manufacturer (the only one in the Nordic region) located in Surahammar
- *SL Technology* – part of the regional transport administration SL (Storstockholms Lokaltrafik) in the Greater Stockholm area
- *SJ* – an operator of passenger trains with headquarters in Stockholm
- *SweMaint* – a maintainer of freight wagons with headquarters in Gothenburg (owned by Kockums Industrier)
- *voestalpine Bahnsysteme* – an Austrian manufacturer of rails and switches with headquarters in Leoben and Vienna (and Zeltweg), respectively

VISION AND GOALS

CHARMEC is a strong player among world-leading research centres in railway mechanics and contributes significantly towards achieving lower production, maintenance, operating and environmental costs and to overall improvement in the safety and quality of railway transportation. The University, Trafikverket and the Industry collaborate in realizing this vision.

CHARMEC successfully combines the identification, formulation and solution of industrially relevant problems with high academic standards and internationally viable research. CHARMEC disseminates its research results and contributes to industrial development and growth in Sweden and abroad.

CHARMEC maintains an up-to-date body of knowledge and preparedness which can be put to use at short notice in the event of unexpected damage or an accident during railway operations in Sweden or abroad. The scientific level and practical usefulness of CHARMEC's academic and industrial achievements are such that continued long-term support to CHARMEC is profitable for the Government, the University and the Industry.

CHARMEC's specific goals include the national training and examination of Licentiates and PhDs and the international presentation and publication of research results. Fundamental and applied research projects are integrated. CHARMEC's industrial partners are supported in the implementation of the solutions that are reached and the use of the tools that are developed. CHARMEC attracts able and motivated PhD students and senior researchers. The Licentiates and PhDs who graduate from CHARMEC make attractive employees in the railway industry and associated R&D organizations.

CHARMEC's research focuses on the interaction of various mechanical components. Analytical, numerical and experimental tools are developed and applied. New and innovative materials, designs and controls are explored. The life-cycle optimization of parts and systems for track structure and running gear is intended to slow down the degradation of ballast and embankments, increase the life of sleepers and pads, improve track alignment stability, reduce rail and wheel wear, reduce the tendency towards rolling contact fatigue of rails and wheels, reduce the levels of vibration and noise in trains, tracks and their surroundings, and improve systems for the monitoring and operation of brakes, bearings, wheels, etc.

BOARD AND DIRECTOR

Karin Markides, President of Chalmers University of Technology, in consultation with Trafikverket and the Industrial Interests Group, appointed the following people as members of the Board of the Competence Centre CHARMEC at the end of Stage 6 (decision dated 2011-12-12):

Annika Renfors (chair)	Trafikverket
Rikard Bolmsvik	Abetong
Henrik Tengstrand	Bombardier Transportation Sweden
Vacant	Faiveley Transport Nordic
Marcin Tubylewicz	Green Cargo
Hugo von Bahr	Interfleet Technology
Erik Kihlberg	Lucchini Sweden
Susanne Rymell	SJ
Laura Mayer	Storstockholms Lokaltrafik (SL)
Tomas Ramstedt	Sweco
Per Gelang	SweMaint / Kockums Industrier
Håkan Anderson	voestalpine Bahnsysteme
Mats Berg	Royal Institute of Tlechnology (KTH)
Per Lövsund	Chalmers Applied Mechanics
Hans Andersson	Chalmers (and SP Technical Research Institute of Sweden)

Björn Paulsson of Banverket resigned as member and chairman of the CHARMEC Board on 31 December 2008 and was then succeeded by Tomas Ramstedt of Banverket (now Trafikverket). Björn Paulsson had held these positions since the start of CHARMEC on 1 July 1995. Annika Renfors of Trafikverket entered upon the duties of Tomas Ramstedt on 1 January 2012. Tomas Ramstedt left Trafikverket on 28 February 2011 for a new employer, the infrastructure consultancy Sweco, but stayed in the CHARMEC Board until 30 June 2012.

Per Lövsund, Head of the Department of Applied Mechanics at Chalmers University of Technology, joined the Board of CHARMEC on 1 July 2009. On the same date, Johan Mårtensson of Faiveley Transport Nordic replaced Roger Jönsson, Erik Kihlberg of Lucchini Sweden replaced Lennart Nordhall and Mats Berg of KTH replaced Stefan Östlund. Also on 1 July 2009, Susanne Rymell of SJ joined the Board of CHARMEC where SJ up to that date had been represented by Hugo von Bahr of Interfleet Technology.

On 1 November 2010, Johan Mårtensson of Faiveley Transport Nordic was succeeded by Tariq Kahn. Per Gelang of SweMaint / Kockums Industrier succeeded Peter Linde on 19 April 2011, and Laura Mayer of SL succeeded Johan Oscarsson, who had left SL for Interfleet Technology, on 1 September 2011. On 31 December 2011, Tariq Kahn of

Faiveley Transport Nordic left the Board. The decisions on these changes by President Karin Markides of Chalmers University are dated 2009-06-17, 2010-11-02, 2011-04-20, 2011-08-26 and 2011-12-12 . The new Board member from Faiveley Transport Nordic is Jan Sterner, see page 123. Roger Lundén, now Professor in Railway Mechanics at Chalmers Department of Applied Mechanics, was appointed Director of the Competence Centre from 1 April 1997. He succeeded the Centre's first Director, Bengt Åkesson, who is now Professor Emeritus of Solid Mechanics. As for Stage 6, President Karin Markides appointed Roger Lundén in her decision dated 2009-06-17. From 1 October 2012, Docent Anders Ekberg will succeed Roger Lundén as Director of CHARMEC (decision by Karin Markides dated 2012-08-29).

The Board of CHARMEC at its meeting on 2 May 2012 in Stockholm

From the left
Fredrik Blennow (representing Faiveley Transport)
Per Lövsund of Chalmers Applied Mechanics (6+7)
Marcin Tubylewicz of Green Cargo (5+6+7)
Hans Andersson of SP Technical Research Institute of Sweden and Chalmers (1+2+3+4+5+6+7)
Håkan Anderson of voestalpine Bahnsysteme (4+5+6+7)
Susanne Rymell of SJ (6+7)
Rikard Bolmsvik of Abetong (5+6+7)
Mats Berg of KTH Railway Group (6)
Erik Kihlberg of Lucchini Sweden (6+7)
Annika Renfors of Trafikverket (Chairperson, 6+7)
Roger Lundén of Chalmers Applied Mechanics (Director of CHARMEC)
Henrik Tengstrand of Bombardier Transportation Sweden (3+4+5+6)
Thomas Ramstedt of Trafikverket , now Sweco (former Chairperson, 5+6)
Hugo von Bahr of Interfleet Technology (1+2+3+4+5+6+7)
Anders Ekberg of Chalmers Applied Mechanics (incoming Director)

Laura Mayer of SL (6)

Per Gelang of SweMaint (6+7)

1 = Board Member Stage 1
2 = Board Member Stage 2
3 = Board Member Stage 3

4 = Board Member Stage 4
5 = Board Member Stage 5
6 = Board Member Stage 6
7 = Board Member Stage 7

QUALITY ASSESSMENT AND KNOWLEDGE TRANSFER

In our opinion, an assessment of the quality and quantity of the results and effects achieved by a Competence Centre like CHARMEC should take the following points into consideration:

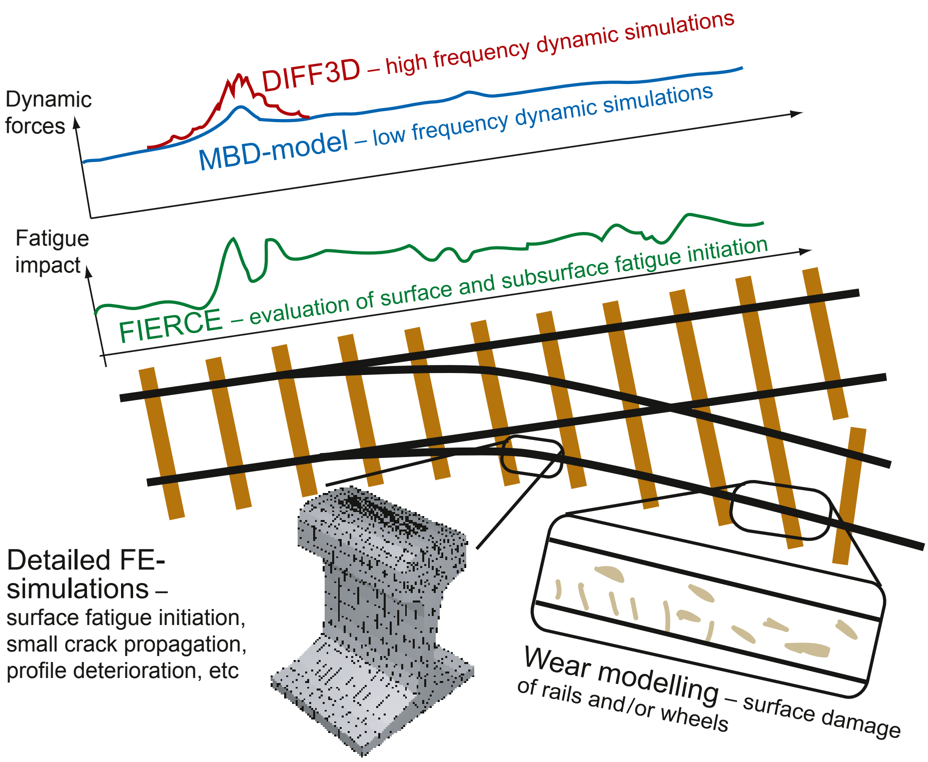
- The ability to understand, formulate and "make scientific" the current problems and aims of Trafikverket and the Industrial Interests Group
- The ability to initiate and run general future-oriented projects within the Centre's field of activity
- The publication of scientific works in recognized international journals
- The publication of read papers in the proceedings of recognized international conferences
- The conferring of Licentiate and PhD degrees and the appointment of Docents (see page 106)
- The transfer to Trafikverket and the Industrial Interests Group of information about the results achieved and the implementation of these results at their sites
- The development, nationally and internationally, of the role of the Centre as a partner for dialogue, as an information hub, and as a network builder

During Stage 6, the scientific quality of CHARMEC's research results has been assured through public presentation and criticism at national licentiate seminars and defences of doctoral dissertations, through the presentation of papers at recognized international conferences and the publication of papers in recognized international journals.

The relevance of our research has been secured through discussions at Board meetings, at seminars at Chalmers with Trafikverket and the industrial partners, and during frequent visits, including brainstorming sessions etc, to industrial sites. Our participation in worldwide railway technology congresses, conferences, symposia, workshops and seminars has also contributed to the calibration of CHARMEC's research.

The transfer of knowledge to Trafikverket and the industry has taken place by means of networking and staff exchanges, through orientation and summarizing at seminars, and through informative reports and the handing over of test results and computer programs. An important part of this knowledge transfer is the employment of people with a Licentiate or PhD degree from the University at Trafikverket or in the industry, either directly or through consulting companies.

Most long-term research projects within the Centre should correspond to five years of work towards a doctoral dissertation. This work should be formulated in general terms with regard to orientation and goals. A detailed specification of each step of a project (such as when an agreement is drawn up for ordering project work or when consultancy services are purchased) should generally be avoided in an academic environment.



Integration of research results from the CHARMEC projects. For DIFF3D and FIERCE, see projects TS4 and MU9 on pages 16 and 43

PROGRAMME AREAS CHARMEC STAGE 6

According to the Principal Agreement for Stage 6, the Competence Centre CHARMEC should work within six overall programme areas as set out below. The choice of projects within each area is decided by the Board of the Centre. These program areas are the same as those during Stages 3, 4 and 5.

Programme area 1
Interaction of train and track
(Samverkan Tåg/Spår, TS)

A rolling train is a mobile dynamic system that interacts, via the wheel/rail interface, with the stationary track structure, which in turn is a dynamic system. This interaction is a key area within all railway mechanics research. The mechanisms behind vibrations, noise and wear depend on the interplay of the rolling train and the track structure. The activities of this programme area are directed towards being able better to understand, model and predict the dynamic interaction for different types and conditions of trains, tracks and operations. Analytical, numerical and experimental methods are used.

Programme area 2
Vibrations and noise
(Vibrationer och Buller, VB)

A considerable reduction in vibrations and noise from railway traffic seems to be of crucial importance to the future acceptance of this type of transportation. The generation and spread of vibrations in trains, tracks and environment and the emission of noise are phenomena that are difficult to approach, both theoretically and experimentally. The activities in this programme area are directed towards achieving a better understanding of the underlying mechanisms. Advanced analytical and numerical tools and well-planned laboratory and field experiments and measurements are required. The goal is to establish a basis for effective modifications and countermeasures against vibrations and noise in trains and tracks and in their surroundings.

Programme area 3
Materials and maintenance
(Material och Underhåll, MU)

Suitable and improved materials for axles, wheels, rails, pads, sleepers, ballast and embankments are a prerequisite for good mechanical performance, reduced wear, lower maintenance costs and an increased technical/economic life of the components mentioned. The activities in this programme area are directed towards analysing existing materials and developing new materials. A knowledge base should be created for the rational maintenance of train and track components. Co-operation between several different competences are required for this research.

Programme area 4
Systems for monitoring and operation
(System för övervakning och Drift, SD)

Brakes, bearings, axles, wheels and bogies are important mechanical components of a train with regard to its operational economy and safety. There seems to be considerable potential for improvement for both passenger and freight trains. New components and new ways of improving and supplementing existing functions should be studied.
A systems approach is emphasized and the work is performed in a cross-disciplinary environment, drawing on several different academic and industrial competences, including solid mechanics, machine elements, signal analysis, control theory, and computer engineering and mechatronics.

Programme area 5
Parallel EU projects
(Parallella EU-projekt, EU)

During Stages 1 to 6, Chalmers University of Technology has been a partner, through CHARMEC, in several EU (European Union) projects in railway mechanics within the Fourth, Fifth, Sixth and Seventh Framework Programmes. All these projects are closely related to CHARMEC's ongoing research in programme areas 1, 2, 3 and 4. CHARMEC contributes to the funding of these EU projects. It should be noted that the legal entity signing EU contracts on our behalf is Chalmers University of Technology.

Programme area 6
Parallel special projects
(Parallella specialprojekt, SP)

At a meeting on 10 September 2002, the CHARMEC Board decided to gather and list a number of our bilateral agreements and separate research and development projects in railway mechanics under the above heading. This programme area includes both short-term and long-term projects, several of which have been established for the industrial implementation of CHARMEC's research results.

SUMMARY OF CHARMEC STAGE 6

Research at the Centre during Stage 6 (1 July 2009 – 30 June 2012) has been carried out as planned. The Board of CHARMEC met as follows:

29 September	2009	9 February	2011
26 November	2009	10 May	2011
4 February	2010	14 September	2011
10 June	2010	29 November	2011
9 September	2010	9 February	2012
2 December	2010	2 May	2012

Detailed minutes were recorded at all meetings. Early decisions were made concerning the content and funding of projects carried over from Stage 5 and of new projects started during Stage 6. As all CHARMEC parties are represented on the Board, the Board meetings have served as an efficient combination of working group and decision-making body. The full-scale outdoor test-stand for braking experiments at Surahammar has been used. International evaluations of CHARMEC were performed in March 1997, March 2000 and March 2003 (see CHARMEC's previous Biennial and Triennial Reports and page 6 in the foregoing). No such evaluations were carried out during Stages 4, 5 and 6.

The NUTEK/VINNOVA ten-year funding of CHARMEC, totalling kSEK 52 300, ended on 30 June 2005. Additional contributions from Banverket/Trafikverket and Chalmers University of Technology replaced the VINNOVA funding during the last year (1 July 2005 – 30 June 2006) of CHARMEC's Stage 4 and during the three years of Stage 5 and the three years of Stage 6. In addition, two separate applications from CHARMEC researchers to VINNOVA during Stage 5 were approved and resulted in three-year funding of the three railway mechanics projects TS11, VB10 and MU18, as reported in the following section. Part of this funding was used during Stage 6. An application to VR (The Swedish Research Council) resulted in three-year funding of project MU25 during Stages 5 and 6. Family Ekman's Research Donation has funded project SD6 during Stages 5 and 6, and is funding project SD9 during Stages 6 and 7. Chalmers has profiled its research activities into eight so-called Areas of Advance (in Swedish: Styrkeområden), see page 127. During Stage 6, CHARMEC researchers have received funding from the Transport Area of Advance, including for the post-doc project VB12. This funding is reported as in-kind contributions.

Through interviews and Road Shows with the CHARMEC partners during 2008, research needs were identified. These needs have influenced the Board's decisions regarding the start of new projects during Stage 6 and will continue to do so during Stage 7. Keywords that summarize the views expressed by Banverket/Trafikverket and the ten companies are:

faster, lighter/heavier,
operationally more reliable,
safer, cheaper, and
environmentally friendlier

When selecting new projects to be run by CHARMEC, the Board has accounted for a proper balance as follows:

fundamental research vs applied research,
doctoral students vs senior researchers,
applicable for the Industry vs
researchable for the University, and
track projects vs vehicle projects

As during Stage 5, Road Shows* were carried out during Stage 6 with visits to Trafikverket and the companies. Also, a corresponding "In-House Show" was arranged at CHARMEC where research staff and doctoral students discussed the future of CHARMEC and presented new ideas. An outcome of this work is a project catalogue comprising 61 project ideas that will be used when selecting new CHARMEC projects.

**A team of senior researchers from CHARMEC visited each one of Trafikverket and the ten partner companies, staged a "Road Show" presenting CHARMEC, and interviewed a group of specially summoned company employees. Our Thomas Abrahamsson (TA), Johan Ahlström (JA), Anders Ekberg (AE), Magnus Ekh (ME), Elena Kabo (EK), Roger Lundén (RL), Jens Nielsen (JN), Christer Persson (CP), Astrid Pieringer (AP), Kenneth Runesson KR), Peter Torstensson (PT), Tore Vernersson (TV) and Bengt Åkesson (BÅ) took part. The visits were as follows from November 2011 to May 2012:*

Lucchini	Surahammar	29 November	AE+RL+TV+BÅ	Interfleet	Solna	16 January	EK+TV
Faiveley	Landskrona	30 November	RL+TV	Bombardier	Västerås	17 January	JA+JN+AP
SL	Stockholm	2 December	AE+RL+PT	SJ	Stockholm	23 January	AE+RL
Abetong	Växjö	21 December	TA+JN	Green Cargo	Solna	29 February	AE+RL
VAE	Zeltweg	12 January	EK+RL+JN	Trafikverket	On telephone	9 March	AE+RL
voestalpine	Zeltweg	12 January	JA+ME+CP+KR	SweMaint	Gothenburg	5 May	RL+TV

The In-House Shows were organized at Chalmers on 22 and 30 March 2012

During Stage 6, a committee from the Board adopted a "CHARMEC Corporate Plan" in which stakeholders, competences, visions, strategies and broad and specific goals etc are identified. Inspired by this, and supported by the information from the Road Shows, the document "CHARMEC Corporate Plan – Focus Areas" was produced. Here, the different forms of co-operation, and the role of CHARMEC, in the deregulated (and partly fragmented) railway sector are described, along with its increased and long-term responsibilities in the research area. Five Focus Areas, in which CHARMEC has a special capability to contribute, were identified: (i) Rails and running gear, (ii) Switches & Crossings, (iii) Sleepers, (iv) Brake systems and (v) Noise. Furthermore, CHARMEC will be increasingly involved in implementation-oriented research (see figure).

Updated overviews and diagrams of the balances are distributed and discussed at Board meetings.

The staff attached to the Centre during Stage 6, both at Chalmers (18 project leaders/principal advisers/senior researchers and 20 PhD students), at Banverket/Trafikverket, and in the Industrial Interests Group (R&D management, technical and experimental staff), have been actively involved. Meetings between university researchers and those working in industry have both led to an increased involvement in long-term industrial knowledge development and to a deeper insight into the working potential of the University. Mutual learning has been achieved.

Eleven licentiate theses and four PhD dissertations in railway mechanics were presented by CHARMEC's doctoral candidates during Stage 6, see page 106. In addition, 32 articles were published (or accepted for publication) in international scientific journals with a referee system, 63 papers were published in the proceedings of international conferences with a referee system, 8 EU reports were delivered, 19 research reports were edited in our own series of English-language research publications, 3 BSc and MSc theses were edited in our own series of student reports (in English), and several other works were published and presented at minor seminars, etc. One of our four new PhDs during Stage 6 continued work as a post-doc at the University and CHARMEC. The remaining three are employed by consultancies where one works full-time within railway mechanics and one is partly involved in railway mechanics.

As with Stages 1, 2, 3, 4 and 5, four seminars (two if not held at Chalmers) are usually scheduled in the morning of days when the Board meets in the afternoon. All CHARMEC board members, project leaders, researchers and others (approximately 120 people) are invited to attend the seminars and the lunch that follows. The seminars, where project leaders/supervisors and PhD students present and discuss their projects, follow a rolling annual schedule. As of Stages 4 and 5, members of the CHARMEC Board and people from Banverket /Trafikverket and the Industrial Interests Group are also scheduled as speakers at some of the morning seminars, where they present their organizations and expectations for CHARMEC. During Stage 6 they were:

Henrik Tengstrand (at Chalmers)	Bombardier	29 Sept	2009
Klas Wåhlberg (in Västerås)	Bombardier	26 Nov	2009
Susanne Rymell (at Chalmers)	SJ	4 Febr	2010
Susanne Rymell (in Stockholm)	SJ	10 June	2010
Mats Berg (in Stockholm)	KTH	2 Dec	2010
Erik Kihlberg (at Chalmers)	Lucchini	9 Febr	2011
Ted Fjällman (in Stockholm)	IVA	10 May	2011
Erik Kihlberg (in Surahammar)	Lucchini	29 Nov	2011
Annika Renfors (at Chalmers)	Trafikverket	9 Febr	2012
Erik Severin (in Stockholm)	Sweco	2 May	2012

Continued participation by CHARMEC researchers in EU projects (Sixth and Seventh Framework Programmes) has expanded our collaboration with companies, universities, institutes, public agencies and consultancies all over Europe. The CHARMEC network linked to EU projects during Stage 6 comprised some 60 organizations in 19 countries; see under projects EU10, EU12 and EU13. We also co-operate with railway bodies in Australia, Canada, India, Japan, South Africa and the USA.

An indication of the high scientific standards achieved in the activities of the University and the Industry at Chalmers Railway Mechanics is the high level of acceptance of articles for journals and contributions to conferences. In total, around 450 such articles and contributions have been published internationally so far. A total of 45 Licentiate degrees and 30 PhD degrees in railway mechanics have been awarded at Chalmers to date (June 2012), see page 106.

CHARMEC runs no undergraduate or graduate courses in railway mechanics as such. However, several undergraduate students have been involved in project work and/or have written their BSc and MSc theses in railway mechanics. A graduate course in contact mechanics with wheel/rail applications was held during Stage 6, see page 115.

It is obvious, in retrospect, that without the framework and support of the NUTEK/VINNOVA Competence Centre concept, the relatively small university-industry collaboration in railway mechanics, which already existed at Chalmers before 1 July 1995, would never have expanded, intramurally and extramurally, nationally and internationally, as it has during the past 17 years of CHARMEC's Stages 1 to 6.

PROJECTS AND RESULTS

The publications listed under the projects have not previously been registered in CHARMEC's Biennial and Triennial Reports 1 July 1995 – 30 June 2009 (Stages 1, 2, 3, 4 and 5), or were incomplete at the time (not yet internationally printed). Several minor reports have been omitted. Internal reports that later resulted in international publication, during the same Stage 6, have also been excluded.

The EU1 – EU5 projects (all now concluded) belonged to Brite/EURAM III under the European Union's Fourth Framework Programme. A list of partners in the EU1 – EU5 projects is presented in CHARMEC's Biennial Report for Stage 1. The EU6, EU7 and EU8 projects (also now concluded) belonged to the Fifth Framework Programme. The scope of the EU6, EU7 and EU8 projects and a list of the partners in these projects are presented in CHARMEC's Triennial Report for Stage 3.

The EU9 and EU10 (and EU11) projects belonged to the Sixth Framework Programme. The total scope of the EU9 and EU10 projects and a list of the partners in EU10 are presented in CHARMEC's Triennial Report for Stage 4. CHARMEC's new European projects EU12 and EU13 belong to the Seventh Framework Programme. It should be noted that external access to EU documents supplied by us and others is often limited.

The departments where the 101 listed CHARMEC projects (TS1 – SP25) are being (or have been) run are as follows. It should be noted that a new research organization at Chalmers University of Technology came into effect on 1 January 2005 when 17 large departments replaced the previous schools and departments. Solid Mechanics, Structural Mechanics and Machine and Vehicle Systems, for instance, are now part of a larger Department of Applied Mechanics. Engineering Metals (later followed by Materials Science and Engineering) is included in the larger Department of Materials and Manufacturing Technology. Applied Acoustics belongs to the new Department of Civil and Environmental Engineering. See page 127.

When a project budget is given as a sum, e g "Stage 4: kSEK 1500+700+350" in project TS8, this signifies that the CHARMEC Board has arrived at several successive budget decisions. As for the project budgets presented for Stage 7, these only include the sums allocated by the Board up until the meeting on 13 September 2012.

The abbreviation Lic Eng stands for the intermediate academic degree *Licentiate of Engineering,* see page 106.

Interaction of train and track – Samverkan tåg/spår (TS) – Wechselwirkung von Zug und Gleis – Interaction entre le train et la voie

TS1. CALCULATION MODELS OF TRACK STRUCTURES

Beräkningsmodeller för spårkonstruktioner
Berechnungsmodelle für Gleiskonstruktionen
Modélisation des structures de voies ferrées

The TS1 project was completed with Johan Oscarsson's successful defence in public of his doctoral dissertation in April 2001, when he also left Chalmers to take up employment with first TrainTech Engineering (now Interfleet Technology) and later Stockholm Public Transport Authority (Storstockholms Lokaltrafik, SL) in Stockholm. Professor Thomas Abrahamsson and Docent (now Professor) Jens Nielsen supervised Johan Oscarsson's research. The title of his dissertation is "Dynamic train/track interaction – linear and nonlinear track models with property scatter". The faculty-appointed external examiner of the dissertation was Dr (now Professor) Søren R K Nielsen from the Department of Structural Engineering at Aalborg University in Denmark.

CHARMEC's simulation model of train–track interaction, developed earlier and implemented in our computer program DIFF, was expanded in order better to reproduce the dynamics of railpads, ballast and subgrade. Measured non-linearities were considered. Stochastic realizations of track models were handled using a perturbation technique. Based on measurements on the Svealand Line in spring 2000, it was found that the scatter in railpad stiffness makes the largest contribution to the variance in the wheel–rail contact force. See also CHARMEC's Triennial Reports for Stages 2 and 3.

Johan Oscarsson is now Regional Director of Interfleet Technology in Sweden. He served on the Board of CHARMEC from November 2007 to August 2011.

PhD student Johan Oscarsson (doctorate earned in April 2001) of project TS1. Photo taken in 2000 in the Chalmers Solid Mechanics laboratory. For photos of Thomas Abrahamsson and Jens Nielsen, see pages 16 and 17

TS2. RAILHEAD CORRUGATION FORMATION

Räffelbildning på rälhuvud
Riffelbildung auf dem Schienenkopf
Formation de l`usure ondulatoire sur le champignon du rail

The TS2 project was completed with Annika Igeland's (now Annika Lundberg) successful defence in public of her doctoral dissertation in January 1997, which was when she also left Chalmers. Tore Dahlberg (then Associate Professor at Chalmers Solid Mechanics) was her supervisor. The faculty-appointed external examiner of the dissertation was Dr (now Professor) David J Thompson from the Institute of Sound and Vibration Research (ISVR) in Southampton, UK. The title of the dissertation is "Dynamic train/track interaction – simulation of railhead corrugation growth under a moving bogie using mathematical models combined with full-scale measurements".

An important feature of the TS2 project was the studied interaction, via the track structure, between the two wheelsets in a bogie. Through numerical simulations, new reflection and resonance phenomena were discovered for the track under a running train. These phenomena manifest themselves with peaks in the spectral density function of the wheel–rail contact force. See also CHARMEC's Biennial and Triennial Reports for Stages 1 and 2.

PhD student Annika Igeland of project TS2 and Dr (now Professor) David J Thompson of ISVR at the defence in public of her doctoral dissertation in January 1997. For a photo of Tore Dahlberg, see page 85

TS3. SLEEPER AND RAILPAD DYNAMICS

Sliprarnas och mellanläggens dynamik
Dynamik der Schwellen und Zwischenlagen
Dynamique des traverses et des semelles de rail

The TS3 project was completed with Åsa Fenander's (now Åsa Sällström) successful defence in public of her doctoral dissertation in May 1997 and her continued work for CHARMEC up until September of the same year, when she left Chalmers. Tore Dahlberg (then Associate Professor at Chalmers Solid Mechanics) was her supervisor. The faculty-appointed external examiner of the dissertation was Professor George A Lesieutre from the Department of Aerospace Engineering at Pennsylvania State University, USA. The title of the dissertation is "Modelling stiffness and damping by use of fractional calculus with application to railpads".

A central feature of the TS3 project was the use of fractional time derivatives for better modelling of the constitutive behaviour of the railpads with their frequency-dependent stiffness and damping. Experimental results from the TNO laboratory in the Netherlands and CHARMEC's Goose Hill measurements in 1993 on the West Coast Line in Sweden were exploited. The application of modal synthesis in mathematical simulations when modelling damping using fractional derivatives was explored. See also CHARMEC's Biennial and Triennial Reports for Stages 1 and 2.

PhD student Åsa Fenander (doctorate earned in May 1997) of project TS3 inspecting an instrumented wheelset in the Chalmers Solid Mechanics laboratory. For a photo of Tore Dahlberg, see page 85

TS4. LATERAL TRACK DYNAMICS

Lateraldynamik och korrugering
Lateraldynamik der Gleiskonstruktionen
Dynamique latérale des voies ferrées

The TS4 project was completed with Clas Andersson's successful defence in public of his doctoral dissertation in June 2003. He continued his work at CHARMEC in the TS7 project up to December 2003, when he left Chalmers. Professor Thomas Abrahamsson and Docent (now Professor) Jens Nielsen supervised Clas Andersson's research. The title of his dissertation is "Modelling and simulation of train/track interaction including wear prediction". The faculty-appointed external examiner of the dissertation was Professor Mats Berg of the KTH Railway Group in Stockholm.

The planar DIFF calculation model developed by CHARMEC was extended to serve as a tool for the analysis of three-dimensional train–track interaction (vertical, lateral and longitudinal) in the frequency range up to approximately 1500 Hz. Both tangent and curved track can be investigated using the new computer program DIFF3D. Large rigid-body movements of the vehicle (important to the low-frequency running dynamics) are permitted simultaneously with small elastic deformations of the contacting components (important to the high-frequency wheel–rail interaction). Both elasticity and creep in the wheel–rail contact zone are studied. Finite element (FE) models of a bogie wheelset and the rail are employed. Like the earlier version DIFF, the new DIFF3D works in the time domain thus allowing for non-linear analyses.

Professor Thomas Abrahamsson (left) and Dr Clas Andersson (doctorate earned in June 2003) of project TS4. Photo taken in 2003

The experimental basis of the track model was developed in full-scale measurements in co-operation with Banverket (now Trafikverket) at Grundbro on a stretch of tangent track on the Svealand Line in spring 2002. Direct and cross accelerances for rails in vertical and lateral directions were registered. Numerical simulations indicate that a high rate of corrugation growth at certain wavelengths corresponds to some specific vibrational modes of the coupled train–track system. Co-operation between the TS4, TS5 and TS7 projects has taken place. See also CHARMEC's Triennial Reports for Stages 2 and 3.

TS5. OUT-OF-ROUND WHEELS – CAUSES AND CONSEQUENCES

Orunda hjul – orsaker och konsekvenser
Unrunde Räder – Ursachen und Konsequenzen
Faux-ronds des roues – causes et conséquences

The TS5 project was completed with Anders Johansson's successful defence in public of his doctoral dissertation in September 2005. Docent (now Professor) Jens Nielsen and Professor Roger Lundén were his supervisors. The faculty-appointed external examiner of the dissertation was Dr (now Professor) Simon Iwnicki from the Department of Engineering and Technology at Manchester Metropolitan University, UK. The title of the dissertation is "Out-of-round railway wheels – causes and consequences: an investigation including field tests, out-of-roundness measurements and numerical simulations".

Railway traffic with out-of-round wheels leads to noise generation and also high dynamic stresses in both track and vehicle with fatigue fracture as the most serious consequence. Wheel tread irregularities occurring in different types of train traffic in Sweden (high-speed, passenger, freight, commuter, subway) were assessed in project TS5. High roughness (corrugation) levels, with wavelengths between 30 mm and 80 mm, were found on tread-braked freight wheels and tread-braked powered X2 high-speed train wheels. The polygonalization of C20 subway wheels in Stockholm was quantified. A calibrated numerical tool for qualitative and quantitative prediction of wheel out-of-roundness and rail corrugation growth was developed. The reference group of project TS5 included members from Banverket (now Trafikverket), Bombardier Transporta-

TS5. (cont'd)

tion and Interfleet Technology and meetings were held in Gothenburg, Stockholm and Siegen (Germany).

In October 2005, Anders Johansson left Chalmers for employment with consultancy Epsilon but has later been contracted temporarily by CHARMEC to assist in several projects, for instance, TS10 and EU10. See also CHARMEC's Triennial Reports for Stages 2, 3 and 4.

From the left: PhD student Elias Kassa (doctorate earned in October 2007) of project TS7, PhD student Anders Johansson (doctorate earned in September 2005) of project TS5, and their supervisor Docent (now Professor) Jens Nielsen. Photo taken at the SweMaint maintenance shop in Gothenburg in 2003

TS6. IDENTIFICATION OF DYNAMIC FORCES IN TRAINS

Identifiering av dynamiska krafter i tåg
Identifizierung von dynamischen Kräften in Zügen
Identification des forces dynamiques dans les trains

The TS6 project was completed with Lars Nordström's successful defence in public of his doctoral dissertation in November 2005, when he also left Chalmers. Professor Thomas Abrahamsson and Dr Peter Möller, Senior Lecturer, were his supervisors. The faculty-appointed external examiner of the dissertation was Professor Anders Klarbring from the Department of Mechanical Engineering at Linköping Institute of Technology in Sweden. The title of the dissertation is "Input estimation in structural dynamics".

The general aim of project TS6 was to study, on a broad scale, possible methods for the calculation of forces acting at locations inaccessible for direct measurements. Starting from a basis of measured accelerations and other responses in appropriate positions and directions onboard a running wagon, attempts should be made to determine the exciting contact forces on the wagon wheels.

A survey of different approaches for indirect input estimation (i e, load identification) has been made for both linear and non-linear systems being either time-invariant or time-variant. The sensitivity of the solutions to the noise that will contaminate measurement data has been examined. A so-called regularization procedure was used to diminish the noise.

Successful numerical experiments were made using synthetic measurement data taken from a discrete model of a two-dimensional generic vehicle and from an FE model of a circular disc (simulating a wheel) with a force travelling around its circumference. Measured data from a full-scale wheelset mounted and excited in the laboratory of Chalmers Applied Mechanics (see photo) were also used. Sensor positions and favourable time delays of sensor signals were investigated. More work in the area of load identification has been carried out in the new project TS12. See also CHARMEC's Triennial Reports for Stages 2, 3 and 4.

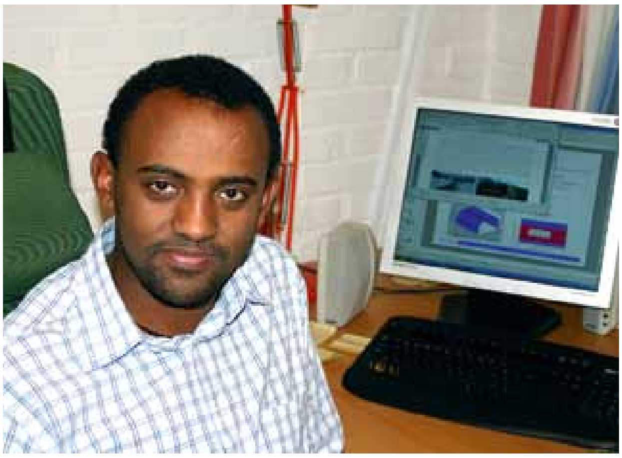
From the left: PhD student Lars Nordström (doctorate earned in November 2005) of project TS6, PhD student Johanna Lilja (licentiate gained in November 2006) of project TS9, and their supervisors Professor Thomas Abrahamsson and Dr Peter Möller. Photo taken in 2003 at the wheelset test rig in the laboratory of Chalmers Solid Mechanics

TS7. DYNAMICS OF TRACK SWITCHES

Spårväxlars dynamik
Dynamik von Eisenbahnweichen
Dynamique des aiguillages de voies ferrées

The TS7 project was completed with Elias Kassa's successful defence in public of his doctoral dissertation in October 2007, when he also left Chalmers. Professor Jens Nielsen was the supervisor of his research work. The faculty-appointed external examiner of the dissertation was Dr Robert D Fröhling from Transnet in the Republic of South Africa. The title of the dissertation is "Dynamic train–turnout interaction – mathematical modelling, numerical simulation and field testing". During the period September 2006 – June 2008, Elias Kassa was initially employed part-time and later full-time by Banverket (now Trafikverket) in Borlänge. He was later active at Manchester Metropolitan University in the UK and is now employed by the Royal Institute of Technology (KTH) in Stockholm. For a photo of Jens Nielsen, see page 17.

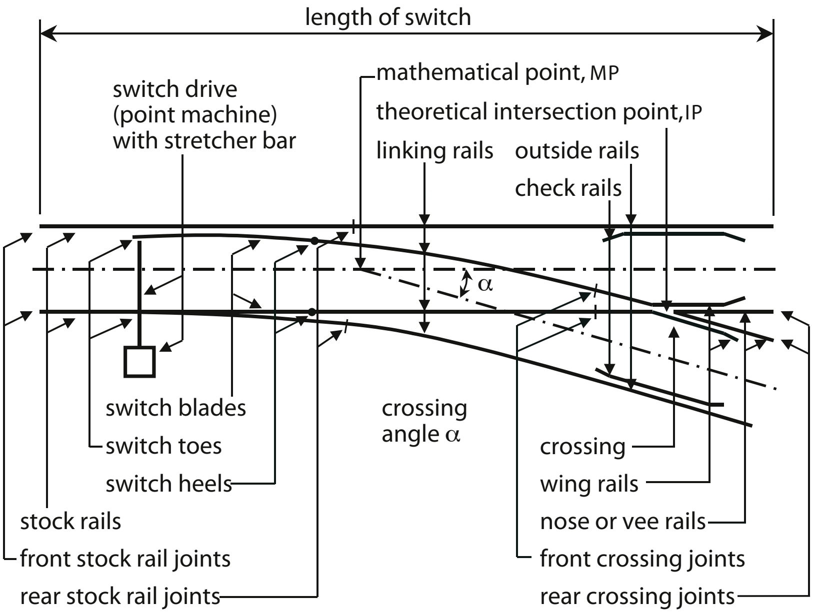
The aim of the TS7 project was to obtain a basic understanding of how railway switches (turnouts) could be developed to achieve lower maintenance costs, fewer traffic disruptions and longer inspection intervals. Usage of the terms switch, turnout and points varies, see the sketch. Multibody system (MBS) models of dynamic interaction between the running train and a standard turnout design (UIC60-760-1:15) have been established. A complex-valued modal superposition of track dynamics was applied to account for the frequency-dependent structural receptance (displacement divided by load) of the track components. Variations in rail profile, track stiffness and track inertia along the turnout, and contact between the back of the wheel flange and the check rail, were considered. Random distributions of the transverse wheel profile and a set of transverse rail profiles along the switch panel were accounted for.



PhD student Elias Kassa (doctorate earned in October 2007) in project TS7. Photo taken in 2006

To determine input data for the turnout model (rail pad stiffness, ballast stiffness and modal damping), impact load testing for measurement of track receptance was performed in the field. Lateral and vertical wheel–rail contact forces were measured using an instrumented wheelset onboard a running train and a good agreement between measured and calculated contact forces was observed. The influence of train speed, moving direction and route on the measured wheel–rail contact forces was quantified. There has been close co-operation with the CHARMEC partner VAE in Austria.

The joint reference group for projects TS7 and MU14 had members from Abetong, Banverket (now Trafikverket), Luleå University of Technology (LTU), Storstockholms Lokaltrafik (SL), VAE and voestalpine Schienen. See also CHARMEC's Triennial Reports for Stages 3, 4 and 5. CHARMEC's work on switches and crossings continues in projects TS13 and TS15, see also projects MU14, SP17 and SP21.



Sketch of a right-hand railway turnout with terminology for "switch and crossing work" according to the European standard EN 13232-1 of September 2003. The tangent of the turnout angle is usually given, e g, tan $\alpha = 1:9$ or 1:12. Often one of the terms "switch" or "turnout" is used for the complete structure consisting of the so-called switch, closure and crossing panels. Switches are sometimes referred to as "points"

TS8. INTEGRATED TRACK DYNAMICS

Integrerad spårdynamik
Integrierte Gleisdynamik
Dynamique intégrée de la voie

Project leader	Professor Jens Nielsen, Applied Mechanics/ Division of Dynamics
Doctoral candidate	None (only senior researcher in this project)
Period	2003-10-01–2012-06-30 (– 2015-06-30)
Chalmers budget (excluding university basic resources)	Stage 4: KSEK 1 500+700+350 Stage 5: KSEK 1 000 Stage 6: KSEK 300 Stage 7: KSEK 200
Industrial interests in-kind budget	Stage 4: KSEK 400 *(Banverket)* Stage 5: KSEK 200+50 Stage 6: KSEK 100+50 Stage 7: KSEK 100+50 *(Banverket/Trafikverket+Abetong)*

For a photo of Jens Nielsen, see page 17

In this work, available software from CHARMEC projects for the analysis of dynamic train–track interaction, of wear and rolling contact fatigue of wheel and rail, and of ground vibrations and railway noise, is being extended and integrated. Calculated high-frequency wheel–rail contact forces have been validated against forces measured by Interfleet Technology during the field tests carried out in October 2002 with an X2 passenger train on rough (corrugated) rails, see projects SP3 and SP11. The application of CHARMEC's computer program DIFF has been broadened to improve the handling of frequencies below 50 Hz. The overall aim of project TS8 is to develop user-friendly computer tools for the rational design of both the whole track and its individual components.

Wear models and creep routines from the in-house code DIFF3D (see project TS4) and from the parallel code FIERCE for evaluation of rolling contact fatigue impact (see project MU9) have been implemented in DIFF and applied in a study of rolling contact fatigue of powered and trailer X2 wheels. Further work on improving the model for simulation of wheel–rail impact loads due to wheel flats and insulated rail joints has been performed (see also project MU18). An accurate measurement of the geometry of wheel flats (radial deviation from the nominal wheel radius) is being performed at SweMaint.

Jens Nielsen participated in the preparation of the successful bid for the EU Seventh Framework Programme project RIVAS, see our project EU12. He has been a member of the scientific committees for the 21st and 22nd IAVSD symposia held in Stockholm (Sweden) in August 2009 and in Manchester (UK) in August 2011, respectively. Jens Nielsen chairs the organizing committee for the 11th International Workshop on Railway Noise (IWRN11) to be hosted by CHARMEC in Uddevalla (Sweden) on 9-13 September 2013, see page 117.

Jens Nielsen: Out-of-round railway wheels, *Wheel-rail interface handbook* (editors Roger Lewis and Ulf Olofsson), *Woodhead Publishing,* Cambridge (UK) 2009, pp 245-279

Jens Nielsen, Oskar Lundberg and Nicolas Renard: Reduction of railway rolling noise by use of rail dampers – results from a field test in Tjörnarp, Research Report 2009:6, *Chalmers Applied Mechanics,* Gothenburg 2009, 63 pp

Jens Nielsen: Inverkan av ökad tåghastighet på vertikal dynamisk kontaktkraft mellan hjul och räl vid en isolerskarv – en parameterstudie (Influence of increased train speed on dynamic contact force between wheel and rail at an insulated joint – a parameter study; in Swedish), Research Report 2011:14, *Chalmers Applied Mechanics,* Gothenburg 2011, 19 pp

TS9. TRACK DYNAMICS AND SLEEPERS

Spårdynamik och sliprar
Gleisdynamik und Schwellen
Dynamique de voie et les traverses

Project leaders and supervisors	Professor Thomas Abrahamsson and Professor Jens Nielsen, Applied Mechanics/ Division of Dynamics
Doctoral candidate	Ms Johanna Lilja (2004-02-09–2010-03-31; Lic Eng November 2006)
Period	2004-01-01–2011-06-30
Chalmers budget (excluding university basic resources)	Stage 4: kSEK 1 825+200 Stage 5: kSEK 1 925+230 Stage 6: kSEK 1 00
Industrial interests in-kind budget	Stage 4: kSEK 300 Stage 5: kSEK 400 Stage 6: kSEK 100 *(Abetong)*

For a photo of Jens Nielsen, see page 17

Project TS9 focused on the design loads for a concrete sleeper installed in a track carrying different types of traffic. Important issues here are the true statistical spread of the loads on the individual sleeper from rails and ballast, the influence of ballast settlements, and the optimal shape of a sleeper. Setting out from test data, a stochastic approach to the modelling of subgrade, ballast and traffic was used and a probabilistic design method for sleepers developed. A so-called sleeper performance function (the probability of cracking because of too high bending moments in the rail seat and centre cross-sections) has been established.

An instrumented sleeper with load-measuring cells (see photo) over its bottom surface was designed and manufactured, and in-field measurements were performed on the Iron Ore Line in Northern Sweden (at Harrträsk close to Gällivare) and on the Southern Main Line (at Torpsbruk and Liatorp close to Alvesta). The use of different sampling frequencies showed that there is an important high-frequency content in the ballast-sleeper load. As to methods for a reliability analysis of sleeper designs, three kinds were investigated: approximate first and second order reliability methods (FORM and SORM), sampling methods that are variations of Latin Hypercube with Importance Sampling, and metamodelling with Monte Carlo Sampling.

Mr Sadegh Rahrovani, MSc, assisted in project TS9. The reference group for the project included members from Abetong, Banverket (now Trafikverket) and Växjö University. See also CHARMEC's Triennial Report for Stage 4 with information on Johanna Lilja's licentiate thesis entitled "Preliminaries for probabilistic railway sleeper design". Johanna Lilja left Chalmers in March 2010 to take up a position with the consultancy FS Dynamics in Gothenburg. Her work at CHARMEC is being continued as part of the new project TS14 where Sadegh Rahrovani is the doctoral candidate.

Sadegh Rahrovani: Test data evaluation from field measurements of sleeper-ballast interface, Research Report 2010:5, *Chalmers Applied Mechanics*, Gothenburg 2010, 53 pp

PhD student Johanna Lilja (licentiate gained in November 2006) and her supervisor Professor Thomas Abrahamsson in project TS9. On the table lies one of the 32 three-point load-measuring cells (i e, adding up to a total 96 sensors) which were placed on the bottom surface of the test sleeper. Photo taken in 2006

TS10. TRACK RESPONSE WHEN USING UNDER SLEEPER PADS (USP)

Spår med sliprar på underlägg
Gleise mit Schwellen auf Zwischenlagen
Voies ferrées avec traverses sur semelles

Project leaders	Dr Rikard Bolmsvik, Abetong, and Professor Jens Nielsen, Applied Mechanics/ Division of Dynamics
Doctoral candidate	None (only senior researchers in this project)
Period	2005-06-01–2012-06-30
Chalmers budget (excluding university basic resources)	Stage 4: kSEK 300+100 kSEK 150+150 *(Christian Berner/ Getzner Werkstoffe+SBB)* Stage 5: kSEK 320 kSEK 150 (*Christian Berner/ Getzner Werkstoffe)* Stage 6: kSEK 100
Industrial interests in-kind budget	Stage 4: kSEK 300+ 100 Stage 5: kSEK 150+150 Stage 6: kSEK 150+150 *(Abetong +Banverket/Trafikverket)*

For a photo of Rikard Bolmsvik and Jens Nielsen, *see page 104*

Under Sleeper Pads (USP) are primarily installed to reduce structure-borne vibrations, maintain track quality index and allow for a prospective reduced depth of the ballast layer. The use of USP could therefore be an interesting alternative to the blasting of bedrock to allow for an increased ballast depth. The objective of project TS10 was to increase the understanding of the influence of USP on the dynamic response of the assembled track structure and its individual components. Several planning and reporting meetings have been held with the manufacturing company Getzner Werkstoffe GmbH (Austria) and their Swedish agency Christian Berner AB, and with Schweizerische Bundesbahnen (SBB Infrastruktur).

Results from field measurements at Kiesen (close to Bern in Switzerland) tally with the results of our numerical parameter study: (i) a low USP stiffness decreases the loading on each sleeper but increases the vertical acceleration of the sleepers, and (ii) a high USP stiffness leads to sleeper responses similar to those obtained for sleepers without USP. It appears that track settlement is slowed down when USPs are used, implying that track quality is being maintained more effectively. For tracks without USP, it has been observed that the track settlement often recurs after renewal of the sleepers and retamping. With USP, the track settlement decreases and appears to approach an almost constant level.

Field measurements have also been performed in the Malmö City Tunnel in Sweden, at one of the transition zones between slab track and ballasted track. The slab track in the tunnel is a so-called LVT-HA (Low Vibration Track – High Attenuation) of a design supplied by Vigier Rail AB. The transition zones, which contain subsections of LVT rubber-booted concrete blocks in a concrete slab, sleepers with USP on ballast, and sleepers without USP on ballast, were designed by SBB Infrastruktur and Vigier Rail. Rail displacements, sleeper accelerations and axle loads were measured by Damill AB.

The stiffness of the transition zone with and without support beams (distribution rails connecting the concrete slab to adjacent sleepers) and the track geometry were measured using Infranord's recording cars STRIX and IMV100. The measurements were funded by Trafikverket, Getzner Werkstoffe, SBB and Vigier Rail. A general observation is that the support beams tend to induce an uplift of the track and a step change in track stiffness. It is suggested that these beams are removed and the consequences of this investigated through repeated measurements of the track geometry. The measurements in the Malmö City Tunnel continue.

Under Sleeper Pads (courtesy Getzner Werkstoffe GmbH)

Philippe Schneider, Rikard Bolmsvik and Jens Nielsen: In-situ performance of a ballasted track with under sleeper pads, *IMechE Journal of Rail and Rapid Transit,* vol 225, no F3, 2011, pp 299-309

Fredrik Jansson and Jens Nielsen: Field measurements of track geometry, stiffness and vibration in a transition zone with under sleeper pads in the Malmö City Tunnel, Research Report 2012:08, *Chalmers Applied Mechanics,* Gothenburg 2012, 33 pp (and 3 appendices, 4+2+4 pp)

TS11. RAIL CORRUGATION GROWTH ON CURVES

Korrugeringstillväxt på räls i kurvor
Zunahme der Riffelbildung auf der Schienenoberfläche in Kurven
Accroissement de l'usure ondulatoire sur les rails dans les courbes

Project leaders and supervisors	Professor Jens Nielsen, Applied Mechanics/ Division of Dynamics, and Dr Anders Frid, Bombardier Transportation Sweden
Doctoral candidate	Mr Peter Torstensson (from 2007-02-26; Lic Eng November 2009)
Period	2005-06-01 – 2012-06-30 (–2012-12-31)
Chalmers budget (excluding university basic resources)	Stage 4: kSEK 125 Stage 5: kSEK 2 050 Stage 6: kSEK 2 400 Stage 7: kSEK 300
Industrial interests in-kind budget	Stage 4: – Stage 5: kSEK 200+50+200 Stage 6: kSEK 200+50+200 *(Banverket/Trafikverket +SL +voestalpine Bahnsysteme)* Stage 7: kSEK 50 *(voestalpine Bahnsysteme)*

The project is partially financed by VINNOVA (through CHARMEC's budget)

For a photo of Anders Frid, see page 99

Corrugation of low rail on a curve of SL track at Stora Mossen in Stockholm

Short-pitch rail corrugation often develops on the low (inner) rail on small radius curves and causes increased noise and vibration levels on railway networks worldwide. In the absence of a generally applicable treatment, track owners are forced to run expensive rail grinding programs on a regular basis to manage these problems. In project TS11, CHARMEC's in-house simulation software DIFF3D has been employed and further developed to model the dynamic interaction between train and track on curves. The model allows for studies of the influence of the level of traction as well as wheel–rail friction, rail cant, curve radius, and non-symmetric rail profiles. The dynamic properties of both vehicle and track are being considered. The distribution of stick and slip over the contact patch between wheel and rail is calculated and used in a wear model for prediction of rail corrugation growth.

In-field measurements have been used to validate both the growth rate of the corrugation and its variation along the curve. Numerical simulations in DIFF3D show that the application of a driving moment on the wheelset results in frequency components of the tangential contact force (resultant to the longitudinal and lateral creep forces) that are determined by the dynamic structural flexibility of the wheelset. These are mechanisms that may trigger the generation of rail corrugation. In particular, the excitation of the first symmetric and the first antisymmetric bending eigenmodes of the leading wheelset in a bogie seems to be strongly related to the corrugation wavelengths observed in the field. Numerical predictions show that corrugation on the low rail develops for a wheel–rail friction coefficient of 0.6, but not for a friction coefficient of 0.3.

This project has been run in co-operation with project VB10. The non-stationary and non-Hertzian contact model developed in project VB10 has been implemented in DIFF3D. A foundation is thus being laid for the prediction of rolling noise emission from a train negotiating a curve.

Measurements of rail corrugation on a curve with a radius of 120 m between Alvik and Stora Mossen on SL's network in Stockholm have been performed, see photo on page 27. These included train speed, rail acceleration, train pass-by noise, friction coefficient, rail profile, and track receptance. Within a rail grinding interval of one year, severe short-pitch corrugation was found to have built up on the low (inner) rail of the SL curve, with maximum peak-to-peak magnitudes of about 0.15 mm. The roughness growth rate increased with time until about 300 days after rail grinding. Thereafter, a more moderate growth rate was observed. Low rail friction management was found to be an effective measure to reduce corrugation growth. The friction modifier and the measurement equipment were provided by Portec Rail Group in Sheffield, UK.

PhD students Peter Torstensson of project TS11 (middle; licentiate gained in November 2009) and Björn Pålsson of project TS13 (right; licentiate gained in April 2011) together with their supervisor Professor Jens Nielsen

Peter Torstensson spent a period at Universidad Politécnica de Valencia in Spain working together with Dr Luis Baeza on implementing a structural dynamics model of a rotating wheelset in our in-house computer program DIFF. The influence of inertial effects due to wheel rotation, such as gyroscopic forces and centrifugal stiffening, on dynamic vehicle–track interaction was investigated. Here, each wheelset resonance peak of multiplicity two splits into two peaks, and the frequency separation of the two peaks increases with increasing rotational speed. If the wheelset model is excited at a frequency where two different mode shapes, due to the wheel rotation, have coinciding resonance frequencies, the magnitude and phase of the contact force calculated for the rotating wheelset model will differ significantly from those of a non-rotating model. In conclusion, the use of a flexible and rotating wheelset model is recommended for load cases leading to large magnitude contact force components at frequencies above 1.5 kHz. Furthermore, for broadband rail roughness excitation, the influence of the radial wheel modes with two or three nodal diameters is significant.

Peter Torstensson presented his licentiate thesis (see below) at a seminar on 27 November 2009 with Dr Roger Enblom of Bombardier Transportation Sweden introducing the discussion. Collaboration between projects TS11 and MU20 has taken place. A computer model representing the conditions in the wear test rig of voestalpine in Leoben (Austria) has been established to calibrate a wear model for the voestalpine 350HT rails used by SL. The research plan for project TS11 is dated 2005-09-15 (with an amendment dated 2005-11-18). The joint reference group for projects TS11 and VB10 has members from Trafikverket and SL Technology and from Bombardier Transportation in Siegen (Germany), Sweden and Switzerland. Peter Torstensson's doctoral dissertation (see below) is planned to be defended on 2012-11-02.

Peter Torstensson: Rail corrugation growth on curves, Licentiate Thesis, *Chalmers Applied Mechanics*, Gothenburg November 2009, 74 pp (Introduction, summary and three appended papers)

Peter Torstensson and Jens Nielsen: On the influence of wheel structural dynamics and the effects of wheel rotation on vertical wheel-rail contact force, Research Report 2010:9, *Chalmers Applied Mechanics,* Gothenburg 2010, 17 pp (also listed under project SP11)

Peter Torstensson, Jens Nielsen and Luis Baeza: High-frequency vertical wheel-rail contact forces at high vehicle speeds – the influence of wheel rotation, *Proceedings 10th International Workshop on Railway Noise (IWRN 10)*, Nagahama (Japan) October 2010, pp 43-50. *Also in Notes on Numerical Fluid Mechanics and Multidisciplinary Design,* vol 118, 2012, pp 43-50

Jim Brouzoulis, Peter Torstensson, Richard Stock and Magnus Ekh: Prediction of wear and plastic flow in rails – test rig results, model calibration and numerical prediction, *Wear,* vol 271, nos 1-2, 2011, pp 92-99 (also listed under project MU20)

Peter Torstensson and Jens Nielsen: Simulation of dynamic vehicle-track interaction on small radius curves, *Vehicle System Dynamics,* vol 49, no 11, 2011, pp 1711-1732

Peter Torstensson, Jens Nielsen and Luis Baeza: Dynamic train-track interaction at high vehicle speeds – modelling of wheelset dynamics and wheel rotation, *Journal of Sound and Vibration,* vol 330, no 22, 2011, pp 5309-5321

Peter Torstensson, Astrid Pieringer and Jens Nielsen: Simulation of rail roughness growth on small radius curves using a non-Hertzian and non-steady wheel–rail contact model, *Proceedings 9th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2012)* , Chengdu (China) August 2012, pp 223-230 (also listed under project VB10)

Peter Torstensson: Rail corrugation growth on curves, Doctoral Dissertation, *Chalmers Applied Mechanics*, Gothenburg November 2012, 145 pp (Summary and six appended papers)

TS12. IDENTIFICATION OF WHEEL–RAIL CONTACT FORCES

Identifiering av kontaktkrafter mellan hjul och räl
Identifizierung von Kontaktkräften zwischen Rad und Schiene
Identification des forces de contact entre roue et rail

Project leaders and supervisors	Docent Fredrik Larsson and Dr Håkan Johansson, Senior Lecturer, Applied Mechanics / Division of Material and Computational Mechanics
Assistant supervisors	Dr Peter Möller, Senior Lecturer, Professor Jens Nielsen and Professor Kenneth Runesson, Applied Mechanics
Doctoral candidate	Mr Hamed Ronasi (from 2007-09-01; Lic Eng September 2010; PhD March 2012)
Period	2007-09-01 – 2012-03-31
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 1300 Stage 6: kSEK 2 550
Industrial interests in-kind budget	Stage 5: kSEK 50+50 Stage 6: kSEK 50+50 *(Bombardier Transportation + Interfleet Technology)*

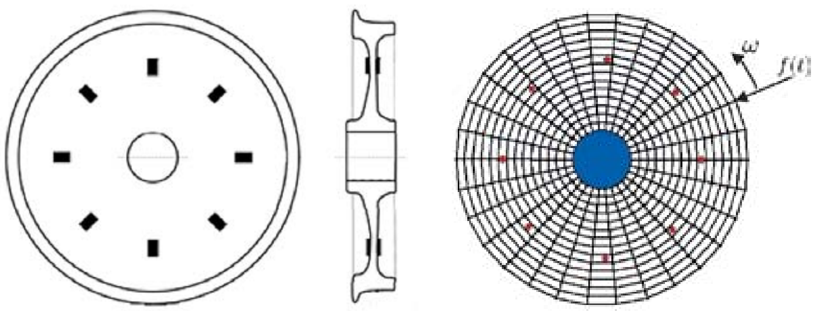
The work to develop methods for more accurate evaluation of the contact forces between wheel and rail began in project TS6 and was further pursued in project TS12. As these forces cannot be measured directly on a rolling wheel, one studied approach has been to register the strain or acceleration at various positions and directions on a wheel or axle and then estimate the forces based on the measured data. However, existing schemes have so far typically involved either a simplified wheel model (neglecting inertia) or, in the case of more advanced models, implied strong restrictions in terms of the choice of spatial and temporal discretization of the underlying equations relating to the motion of the wheel.

In the current project, the vertical contact force is determined through the solution of an inverse problem (see figure). A mathematical minimization problem is considered in which the sought time history of the contact force is such that the discrepancy between the predicted (based on finite element analysis) and the measured response (strains) is minimized. A particular feature of this formulation is that the discretization of the pertinent state equations in space-time, the sampling instances of the measurements, and the parameterization of the sought contact force are all independent of each other.

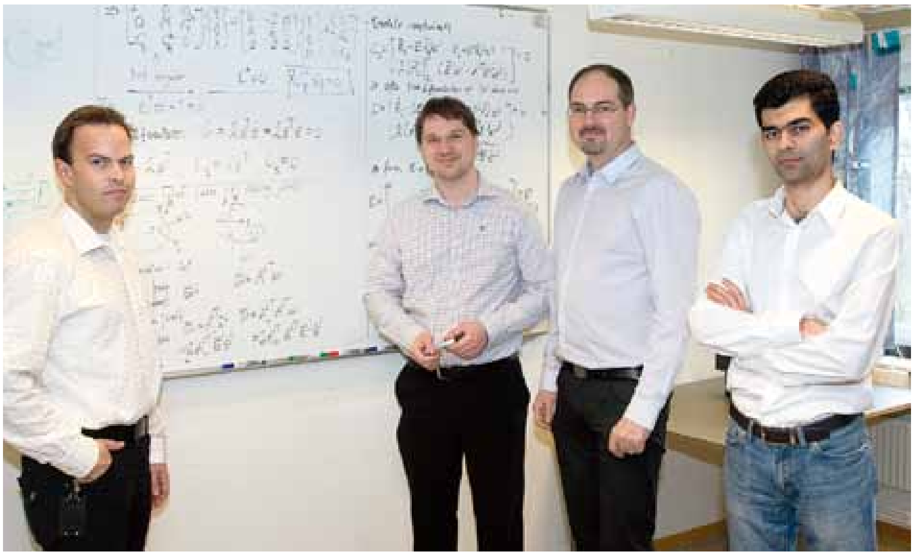
The proposed strategy was first evaluated for the simplified case of a two-dimensional (2D) rolling disc (see sketch) with focus on the effects of discretization and sensitivity to noise, and of a possible improvement resulting from proper regularization. Effects of considering different measurement outputs for the minimization problem were also investigated. Secondly, the identification procedure was applied to a three-dimensional (3D) finite element model of a Regina train wheelset from Bombardier Transportation. The disturbing influence of vibrations in the wheel eigenmodes (see figure) was eliminated and good results were obtained for vertical contact forces with a frequency content of up to 2000 Hz. Upon considering synthetic data obtained by use of the in-house code DIFF for two load cases (periodic rail irregularity and insulated rail joint), a comparison with two other numerical algorithms was made. A remaining problem is the evaluation of the lateral and longitudinal contact forces.

Hamed Ronasi's licentiate seminar was held on 24 September 2010 with Dr (now Professor) Torbjörn Ekevid (see project VB5) from the Linnæus University in Kalmar/Växjö (Sweden) introducing the discussion. The TS12 project was concluded with Hamed Ronasi's successful defence in public of his doctoral dissertation (see below) on 29 March 2012, which was also when he left Chalmers for a position with L B Foster / Kelsan Technologies in Vancouver (Canada). The faculty-appointed external examiner of the dissertation was Professor Tadeusz Uhl from the Faculty of Mechanical Engineering and Robotics at the AGH University of Science and Technology in Kraków, Poland.

The research plan for project TS12 is dated 2007-01-22. The joint reference group for projects TS12 and SD6 had members from Bombardier Transportation Sweden and Interfleet Technology.



Rolling railway wheel instrumented with strain gauges as used by Interfleet Technology in field measurements (left) and non-rotating 2D model with rotating load studied in project TS12 (right)



PhD student Hamed Ronasi (right; doctorate earned in March 2012) in project TS12 and his supervisors Docent Fredrik Larsson (left), Dr Håkan Johansson (second from the left) and Professor Jens Nielsen. Photo taken in 2009. For photos of Dr Peter Möller and Professor Kenneth Runesson, see pages 17 and 39

Hamed Ronasi: Towards the identification of wheel-rail contact forces, Licentiate Thesis, *Chalmers Applied Mechanics*, Gothenburg September 2010, 53 pp (Introduction and two appended papers)

Hamed Ronasi, Håkan Johansson and Fredrik Larsson: A numerical framework for load identification and regularization with application to rolling disc problem, *Computers & Structures,* vol 89, nos 1-2, 2011, pp 38-47

Hamed Ronasi, Håkan Johansson, Fredrik Larsson and Jens Nielsen: A strategy for the identification of wheel-rail contact forces based on indirect measurement and finite element model of the rolling wheel, Poster at *International Heavy Haul Association Specialist Technical Session* (IHHA STS 2011), Calgary (Canada) June 2011 (documented on CD)

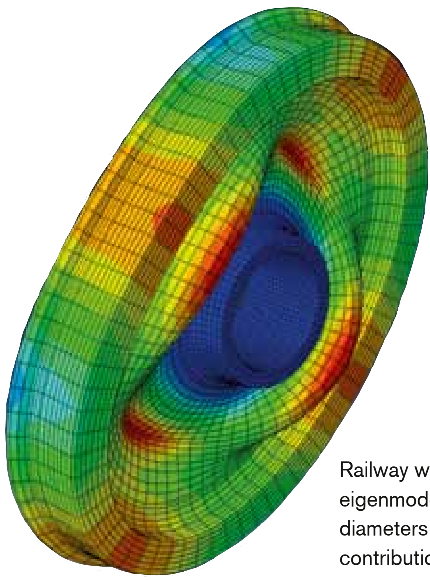
Hamed Ronasi, Håkan Johansson and Fredrik Larsson: Identification of wheel-rail contact forces based on strain measurement and finite element model of the rolling wheel, *30th International Modal Analysis Conference (IMAC XXX),* Jacksonville FL (USA) January-February 2012, 8 pp, *Conference Proceedings of the Society for Experimental Mechanics,* part 31, no 6

Hamed Ronasi, Håkan Johansson and Fredrik Larsson: Load identification for a rolling disc: finite element discretization and virtual calibration, *Computational Mechanics,* vol 49, no 2, 2012, pp 137-147

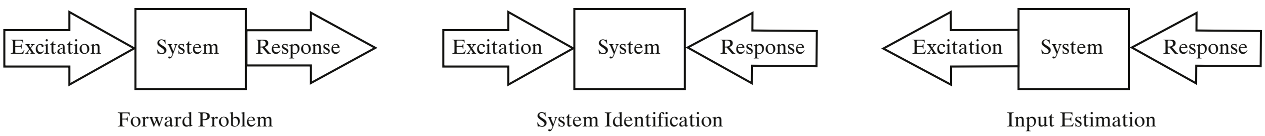
Hamed Ronasi and Jens Nielsen: Inverse identification of wheel-rail contact forces based on observation of wheel disc strains – an evaluation of three numerical algorithms, *Vehicle System Dynamics* (accepted for publication)

Hamed Ronasi, Håkan Johansson and Fredrik Larsson: Identification of wheel-rail contact forces, an inverse scheme and finite element model of the wheel (submitted for international publication)

Hamed Ronasi: Inverse identification of dynamic wheel-rail contact forces, Doctoral Dissertation, *Chalmers Applied Mechanics,* Gothenburg March 2012, 89 pp (Summary and five appended papers)



Railway wheel vibrating in eigenmode with two nodal diameters causing significant contributions to strains at gauge positions



Problems in mechanical system dynamics. Project TS12 deals with the problem to the right

TS13. OPTIMIZATION OF TRACK SWITCHES

Optimering av spårväxlar
Optimierung von Eisenbahnweichen
Optimisation des aiguillages de voies ferrées

Project leaders and supervisors	Professor Jens Nielsen and Professor Thomas Abrahamsson, Applied Mechanics / Division of Dynamics
Doctoral candidate	Mr Björn Pålsson (from 2008-09-01; Lic Eng April 2011)
Period	2008-09-01 – 2012-06-30 (–2014-02-28)
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 650 Stage 6: kSEK 2 550 Stage 7: kSEK 1 100
Industrial interests in-kind budget	Stage 5: kSEK 200 (*voestalpine)* Stage 6: kSEK 200+50+200 *(Banverket/Trafikverket + SL +voestalpine Bahnsysteme)* Stage 7: kSEK 200+25+100 *(Trafikverket + SL +voestalpine Bahnsysteme)*

For photos of Jens Nielsen, Thomas Abrahamsson and Björn Pålsson, see pages 23 and 28

Switches & Crossings (S&C, turnouts, points) are composed of a switch panel and a crossing panel connected by a closure panel, see sketch on page 18. Only in Sweden there are over 12 000 turnouts in its some 17 000 km of track, and S&C account for a considerable part of reported track faults. In project TS13, numerical methods are being developed for the optimal design of S&C aiming at a reduction of dynamic wheel–rail contact forces and subsequent S&C component degradation. Examples of design variables used in the optimization are rail profile, stiffness of resilient layers (such as rail pads and under sleeper pads), and nominal track gauge variation in the switch panel. The methods used take into account the stochastic distribution (scatter) of load parameters such as worn wheel profiles, as well as varying train speed, axle load and wheel–rail friction. Models for the simulation of dynamic interaction between train and switch, as developed in the earlier project TS7, are being employed. Project TS13 has been run in co-operation with project EU10.

To investigate the stochastic spread in traffic parameters, qualitative and quantitative estimates of rail profile degradation in S&C have been computed. The influence of wheel profile wear on wheel–rail interaction in a turnout has been studied, and it was concluded that equivalent conicity is a wheel profile characterization parameter with good correlation to rail damage, i e, a small equivalent conicity increases the likelihood of large amounts of wear in the switch panel. The influence of hollow-worn wheels on rail damage was also investigated, and it was found that such wheels display a significantly different and potentially more harmful running behaviour at crossings. The wheel–rail friction coefficient correlates strongly to lateral contact forces and wear in the diverging route. In addition to this, wheelset steering is also being studied. Good agreement between the simulation model and field measurement data has been observed. It is concluded that the use of more resilient rail pads can reduce wheel–rail impact loads during the train's crossing transition.

Wheel profiles measured at SweMaint and Cargonet in Gothenburg have been analysed and classified with respect to equivalent conicity and standardized quantities for wheel wear. A track model that takes into account space-dependent properties and track dynamics in an extended frequency range has been implemented into the commercial software GENSYS. The GENSYS track model was validated using data from Trafikverket's RSMV (Rolling Stiffness Measurement Vehicle) and track receptance measurements performed in the INNOTRACK project EU10 on switches at Eslöv (Sweden).

A methodology for reducing rail profile degradation in the switch panel by using an optimized prescribed track gauge variation (gauge widening) has been developed. A holistic approach is applied, where the two routes and the two travel directions (moves) of traffic in the switch panel are considered in parallel. The problem is formulated as a multi-objective minimization problem, which is solved using a genetic-type optimization algorithm providing a set of Pareto-optimal solutions. The dynamic vehicle–turnout interaction was evaluated and low energy dissipation in the wheel–rail contact was used for the assessment of good gauge parameters. Two different vehicle models were studied, one freight car and one passenger train set, and a stochastic spread in wheel profile and wheel–rail friction coefficient was accounted for. It was found that gauge configurations with a large gauge widening amplitude for the stock rail on the field side are optimal for both the through route and the diverging route, while the results for the gauge side show greater route dependence. It was observed that the optimal gauge configurations were similar for both vehicle types. Low energy dissipation and low normal pressure in the wheel–rail contact in the switch panel have also been studied, as objective functions in an optimization of the rail profile, which is here described through spline functions with four free parameters. The results can be used when setting the milling parameters in the switch rail manufacturing plant.

Björn Pålsson presented his licentiate thesis (see below) at a seminar on 14 April 2011 with Dipl-Ing Dirk Nicklisch of DB Netz introducing the discussion. The reference group for project TS13 has members from Trafikverket, SL Technology and VAE. In parallel to his work in TS13, Björn Pålsson contributes to the EU13, SP17 and SP24 projects and his period of employment in CHARMEC has therefore been extended. The research plan for project TS13 is dated 2008-08-29.

Björn Pålsson and Jens Nielsen: Damage in switches and crossings considering stochastic spread in traffic parameters, *Proceedings 10th International Conference on Recent Advances in Structural Dynamics (RASD 2010)*, Southampton (UK) July 2010, 12 pp (documented on USB)

Rikard Bolmsvik, Jens Nielsen, Per Kron and Björn Pålsson: Switch sleeper specification, Research Report 2010:3, *Chalmers Applied Mechanics*, Gothenburg 2010, 54 pp (also listed under project SP17)

Björn Pålsson and Jens Nielsen: Damage in switches and crossings, *16th Nordic Seminar on Railway Technology,* Nynäshamn (Sweden) September 2010, 1+32 pp (Summary and PowerPoint presentation. Documented on CD)

Björn Pålsson: Towards optimization of railway turnouts, Licentiate Thesis, *Chalmers Applied Mechanics*, Gothenburg April 2011, 53 pp (Introduction and three appended papers)

Björn Pålsson and Jens Nielsen: Track model validation for simulation of train-turnout dynamics, Poster at *International Heavy Haul Association Specialist Technical Session (IHHA STS 2011),* Calgary (Canada) June 2011 (documented on CD)

Björn Pålsson and Jens Nielsen: Kinematic gauge optimization of switches using genetic algorithms, *Proceedings 22nd IAVSD Symposium on Dynamics of Vehicles on Roads and Tracks,* Manchester (UK) August 2011, 6 pp (documented on CD). At the symposium this paper was presented by Björn Pålsson and received the Taylor & Francis Best Oral Paper Award

Björn Pålsson and Jens Nielsen: Wheel–rail interaction and damage in switches and crossings, *Vehicle System Dynamics,* vol 50, no 1, 2012, pp 43-58

Björn Pålsson and Jens Nielsen: Track gauge optimisation of railway switches using a genetic algorithm, *Vehicle System Dynamics,* vol 50, supplement no 1, 2012, pp 365-387

Björn Pålsson and Jens Nielsen: Design optimization of switch rails in railway turnouts, *Proceedings 9th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2012),* Chengdu (China) August 2012, pp 655-665

SL metro train of type C20 on a curve at Stora Mossen in Stockholm, as studied in project TS11. Each year approximately 80 000 trains pass in each direction at a speed of about 30 km/h

TS14. MULTICRITERION OPTIMIZATION OF TRACK PROPERTIES

Multikriterieoptimering av spåregenskaper
Mehrfaches Kriterium für Optimierung der Gleiseigenschaften
Critère multiple pour l'optimisation des propriétés de la voie

Project leaders and supervisors	Professor Thomas Abrahamsson and Professor Jens Nielsen, Applied Mechanics / Division of Dynamics
Doctoral candidate	Mr Sadegh Rahrovani, MSc (from 2011-03-01)
Period	2011-03-01 – 2012-06-30 (–2016-02-29)
Chalmers budget (excluding university basic resources)	Stage 6: kSEK 1800 Stage 7: kSEK 3100
Industrial interests in-kind budget	Stage 6: kSEK 200 Stage 7: kSEK 100 *(Abetong)*

This project focuses on the optimal properties of a railway track, with the design parameters for optimization being related to the railway sleeper and those track components which interface the sleeper. The optimization is multicriterion in the sense that it targets both the failure strength of the sleeper and the geometric stability of the track. Since track properties vary significantly in space and time, a stochastic approach to the optimization is taken. The optimization will rely on fast simulations, and dual level modelling will be used. At the first stage, a detailed model based on first principles will be calibrated and validated to test results. At the second stage, a substantially simplified surrogate model will be established, with input-output relations that mimic those of the detailed model. The surrogate model will be used for optimization and the detailed model for error control. Results obtained in the previous project TS9 are utilized.

In order to decrease the simulation time of the in-house code DIFF, which was updated to capture non-linear ballast behaviour in project TS9, the performance of the code has been improved by choosing an appropriate non-linear solver, writing more efficient MATLAB routines, and reducing the order of the problem. Sadegh Rahrovani attended a course on Nondeterministic Mechanics at the CISM (Centre International des Sciences Mécaniques) Advanced School in Udine (Italy) in May 2011.

A track model has been established to study the identifiability of track parameters such as local ballast stiffness, and a possible gap between sleeper and ballast (under what is referred to as a hanging sleeper). The results are being used in a test set-up for upcoming field measurements, where an instrumented steel sleeper will be employed. These measurements are planned in co-operation with Abetong.

The research plan for project TS14 is dated 2010-05-31. The reference group for the project has members from Abetong, Dr Plica Ingenieure in Munich (Germany) and Trafikverket.

Majid Khorsand Vakilzadeh, Sadegh Rahrovani and Thomas Abrahamsson: An improved model reduction method based on input-output relation, *Proceedings International Conference on Noise and Vibration Engineering (ISMA 2012-USD 2012)*, Leuven (Belgium) September 2012, pp 3451-3459

PhD student Sadegh Rahrovani (right) and his supervisor Professor Thomas Abrahamsson from project TS14. For a photo of Professor Jens Nielsen see page 29

TS15. IMPROVED AVAILABILITY AND REDUCED LIFE CYCLE COST OF TRACK SWITCHES

Förbättrad tillgänglighet och minskad livscykelkostnad för spårväxlar
Verbesserte Verfügbarkeit und verminderte Lebenszykluskosten für Gleisweichen
Amélioration de la disponibilité et réduction des coûts du cycle de vie des aiguillages

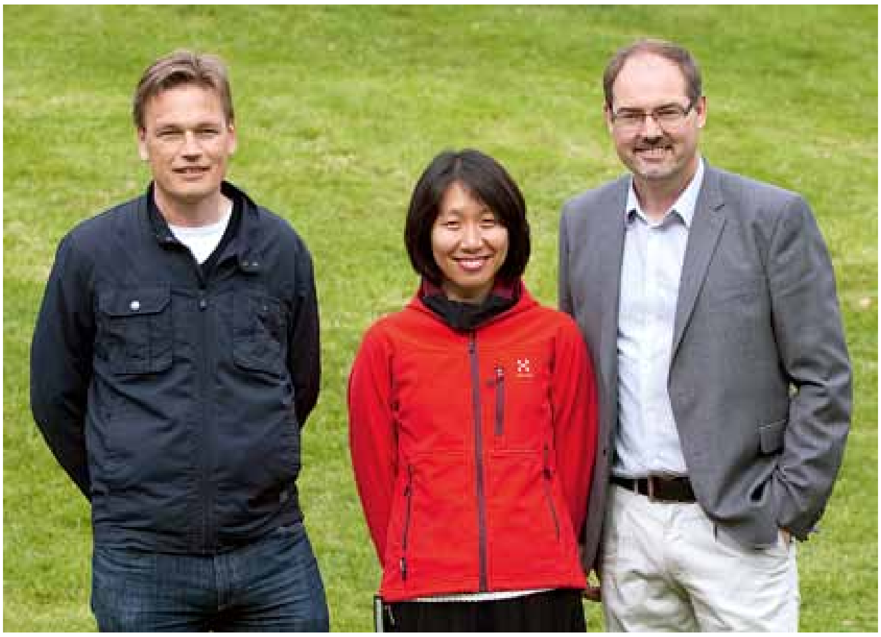
Project leaders and supervisors	Professor Jens Nielsen, Applied Mechanics / Division of Dynamics, and Professor Magnus Ekh, Applied Mechanics / Division of Material and Computational Mechanics
Doctoral candidate	Ms Xin Li, MSc (from 2012-01-09)
Period	2012-01-09 – 2012-06-30 (–2017-01-31)
Chalmers budget (excluding university basic resources)	Stage 6: kSEK 865 Stage 7: kSEK 2 775
Industrial interests in-kind budget	Stage 6: kSEK – Stage 7: kSEK 200+100+100 *(Trafikverket+Abetong +voestalpine Bahnsysteme)*

The project is financed by Trafikverket via Luleå Technical University (LTU)

The aim of this project is to develop methods that will reduce the need for maintenance of switches and crossings (S&C), thereby bringing down traffic disturbances and life cycle costs. In particular, the knowledge of parameters affecting track geometry degradation caused by the settlement of ballast and soil will be increased. Product development of S&C, based on optimal use of resilient elements, and leading to lower dynamic forces and improved geometric stability, will be supported. Models of dynamic interaction between vehicle and S&C, and finite element calculations of stresses and strains in relevant S&C components and ballast/soil, will be used to predict wheel–rail contact forces and track geometry degradation. A stochastic distribution of load parameters such as amount of wear of wheel profiles and variations in train speed, axle load, and wheel–rail friction will be considered. The methodology developed in INNOTRACK (see project EU10) and project TS13 will be applied. The present project is being run in co-operation with a parallel PhD project at Luleå University of Technology (LTU) and its railway research centre (JVTC).

Xin Li participated in the INNOTRACK workshop on innovative S&C development in Eslöv (Sweden) on 14-15 February 2012 and attended a meeting with LTU in Luleå on 24 May 2012. A literature survey on settlement in railway tracks has been initiated. A methodology for the simulation and prediction of track settlement in S&C and its consequences is being developed. Xin Li attended the CM2012 conference in Chengdu (China) in August 2012.

The reference group for project TS15 and the parallel project at LTU has members from Abetong, VAE, Vossloh Nordic and Trafikverket. The research plan for project TS15 is dated 2011-06-13.



PhD student Xin Li and her supervisors Professor Jens Nielsen (right) and Professor Magnus Ekh from project TS15

VB1. STRUCTURAL VIBRATIONS FROM RAILWAY TRAFFIC

Byggnadsvibrationer från järnvägstrafik
Gebäudeschwingungen durch Eisenbahnverkehr
Vibrations de bâtiments causées par le traffic ferroviaire

For a photo of Johan Jonsson, see page 32

Project VB1 was completed with Johan Jonsson's successful defence in public of his doctoral dissertation in June 2000. Professor Sven Ohlsson and Professor Thomas Abrahamsson supervised the research. The faculty-appointed external examiner of the dissertation was Dr Christian Madshus from the Norwegian Geotechnical Institute (NGI) in Oslo, Norway. The title of the dissertation is "On ground and structural vibrations related to railway traffic".

An important conclusion from the project was that only low-frequency vibrations are effectively transmitted from a passing train through the ground into a nearby building foundation. Two- and three-dimensional analytical and numerical models were developed and applied. Extensive multi-channel field measurements (in three directions, both at ground surface level and at a depth of 6 m below the ground surface) were performed beside the railway at Alvhem north of Gothenburg, where clay is found to a depth of approximately 40 m. Structural vibrations were measured at the same place on a specially designed concrete slab (0.12 m × 9.00 m × 10.00 m) constructed later on a gravel bed with steel frames of different resonance frequencies mounted on it. By use of compressed air in preplaced hoses under the slab, this could later be lifted from the ground for a separate measurement of its dynamic properties including the steel frames.

See also CHARMEC's Biennial and Triennial Reports for Stages 1 and 2.

Vibrations and noise – Vibrationer och buller (VB) – Schwingungen und Geräusche – Vibrations et bruit

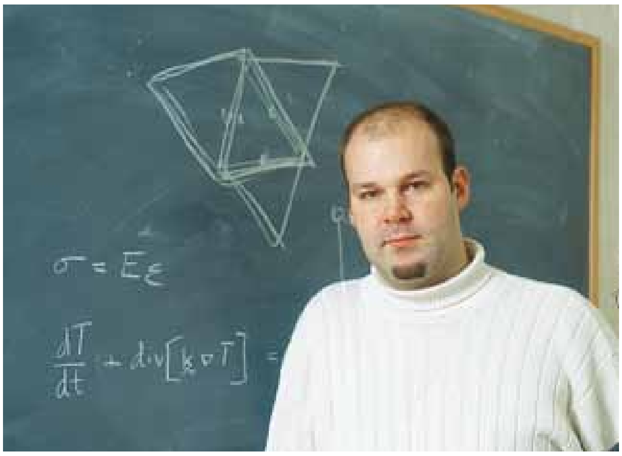
VB2. NOISE FROM TREAD BRAKED RAILWAY VEHICLES

Buller från blockbromsade järnvägsfordon
Rollgeräusche von Zügen mit Klotzbremsen
Bruit émis par les trains freinés par sabot

Freight trains run to a large extent at night, and have also proved noisier than passenger trains. The reason for the latter is that freight trains are nearly always tread-braked while passenger trains are disc-braked. Thermal interaction between the wheel and the brake blocks causes a corrugated tread on the wheel. For the running train this results in oscillating contact forces that excite vibrations in the wheel and rail, with noise radiation as a consequence.

Extensive braking experiments were performed on the test rig (inertia dynamometer) at Surahammar, see page 73, and mathematical modelling and numerical simulations were carried out. Brake blocks of cast iron, sintered material and composite material were investigated. Surface temperatures were measured with an IR camera and the tread waiviness (after cooling) with a mechanical displacement probe. See CHARMEC's Biennial and Triennial Reports for Stages 1, 2 and 3, and also project SD4 below.

Project VB2 was led by Professor Roger Lundén assisted by Dr Peter Möller. The doctoral candidate Martin Petersson gained his licentiate in the project in October 1999 but then left Chalmers for employment with Volvo Trucks. The title of his licentiate thesis is "Noise-related roughness of railway wheels – testing of thermomechanical interaction between brake block and wheel tread".



PhD student Martin Petersson (licentiate gained in October 1999) of project VB2. Photo taken in 2000. For photos of Roger Lundén and Peter Möller, see pages 31 and 17

Tore Vernersson was also involved in VB2 and gained his licentiate in that project but later transferred to projects VB3, VB4, EU1, EU8 and SD4. He earned his doctorate in June 2006 in project SD4, see page 106.

Vibrations and noise – Vibrationer och buller (VB) – Schwingungen und Geräusche – Vibrations et bruit

VB3. TEST RIG FOR RAILWAY NOISE

Provrigg för järnvägsbuller
Prüfstand für Eisenbahnlärm
Banc pour d´essai pour le bruit ferroviaire

The Railway Noise Test Rig (RNTR) has been designed and constructed as planned, and the VB3 project was completed on 30 June 2000. A 25 m stretch of full-scale track with UIC60 rails is used. A further development of the rig has taken place in the VB4 project. The RNTR was built outdoors on the Adtranz Wheelset (now Lucchini Sweden) factory site in Surahammar. A special feature of RNTR is that wheelset and track, which are not in mechanical contact, can be excited both together and separately (three different tests with the same excitation). The level and directivity of sound from a wheelset (or a bogie) and the track can thereby be established both in total and separately. Microphone sweeps are performed over a quarter of a spherical surface. The track can be statically preloaded.

See also CHARMEC's Biennial and Triennial Reports for Stages 1, 2 and 3.

Vibrations and noise – Vibrationer och buller (VB) – Schwingungen und Geräusche – Vibrations et bruit

VB4. VIBRATIONS AND EXTERNAL NOISE FROM TRAIN AND TRACK

Vibrationer och externbuller från tåg och spår
Schwingungen und externe Geräusche von Zug und Gleis
Vibrations et bruit extérieur émis par le train et la voie

With higher speeds and axle loads, railway traffic is an increasing source of noise pollution in the community. A predominant part of the noise-generating vibrations stems from the contact between wheel and rail because of irregularities on the running surfaces. The VB4 project has used and developed the RNTR, see VB3. It can demonstrate how the vibration and noise properties of various track and onboard components can be predicted for the running train.

Project VB4 was led by Professor Roger Lundén assisted by Dr Anders Frid of Bombardier Transportation Sweden and Docent (now Professor) Jens Nielsen. The doctoral candidate Carl Fredrik Hartung left Chalmers after obtaining his licentiate in November 2002. The VB4 project was then partially discontinued. The title of the licentiate thesis is "A full-scale test rig for railway rolling noise".

Visualization of the noise emitted from a wheel prototype as measured in the RNTR at frequency 875 Hz in project VB4. Red indicates a high level of sound pressure and blue indicates a low level. A reflecting ground surface is used in this experiment. Photo taken in 2002

Tore Vernersson contributed early in the project and resumed work with the RNTR during Stage 5 with funds remaining from Stage 4. See CHARMEC's Triennial Reports for Stages 2 and 3 and also the new projects VB10 and VB11 on noise emission.

From the left: PhD student Tore Vernersson (doctorate earned in June 2006), the supervisor Professor Roger Lundén, and PhD student Carl Fredrik Hartung (licentiate gained in November 2002). Photo taken in 2000. For a photo of Dr Anders Frid and Professor Jens Nielsen, see page 99

VB5. WAVE PROPAGATION UNDER HIGH-SPEED TRAINS

Vågutbredning under höghastighetståg
Wellenausbreitung unter Hochgeschwindigkeitszügen
Propagation d´ondes sous des trains à grande vitesse

Project VB5 was completed with Torbjörn Ekevid's successful defence in public of his doctoral dissertation in December 2002 and his continued work in the project until March 2004. Professor Nils-Erik Wiberg from the Department of Structural Mechanics was his supervisor. The faculty-appointed external examiner of the dissertation was Professor Roger Owen from the Department of Civil Engineering at the University of Wales in Swansea, UK. The title of the dissertation is "Computational solid wave propagation – numerical techniques and industrial applications". The project was partially financed by the Swedish Foundation for Strategic Research (SSF) through its National Graduate School in Scientific Computation (NGSSC).

At places in Sweden where ground conditions are poor with deep layers of soft clay, high vibration levels have been observed on the embankment and surrounding ground when high-speed trains passed. A shock, similar to that experienced when an aircraft breaks the sound barrier, occurs when the increasing speed of the train exceeds the Rayleigh wave speed on the ground. On certain stretches of track in Sweden, the maximum permissible train speed has had to be reduced. By means of numerical simulations and parallel in-field measurements at Ledsgård on the West Coast Line south of Gothenburg, the VB5 project has provided an understanding of which factors affect the vibration levels. Parametric studies have clarified the roles of the speed of the train and the properties of the clay. One measure to reduce the ground vibrations is the installation of lime-cement columns, see project VB9 which was partly a continuation of VB5. See also CHARMEC's Triennial Reports for Stages 2, 3 and 4.

From the left: Dr Torbjörn Ekevid (doctorate earned in December 2002) and his supervisor Professor Nils-Erik Wiberg in project VB5. Photo taken in 2003

VB6. INTERACTION OF TRAIN, SOIL AND BUILDINGS

Interaktion mellan tåg, mark och byggnader
Wechselwirkung von Zug, Boden und Gebäuden
Interaction entre train, sol et bâtiments

The VB6 project was intended as a continuation of VB1 with a greater orientation towards constructive measures for the reduction of vibrations in buildings beside the track. The project was terminated (prematurely) in December 2001 when Johan Jonsson left Chalmers for employment elsewhere. Project VB8 partially replaced VB6.

Dr Johan Jonsson of the VB1 and VB6 projects (doctorate earned in June 2000). Photo taken in 2003

VB7. VIBRATION TRANSMISSION IN RAILWAY VEHICLES

Vibrationsöverföring i järnvägsfordon
Schwingungsübertragung in Eisenbahnfahrzeugen
Transmission de vibrations dans les véhicules ferroviaires

Project VB7 was completed with Per Sjövall's successful defence in public of his doctoral dissertation in November 2007. Professor Thomas Abrahamsson, Applied Mechanics, and Professor Tomas McKelvey, Signals and Systems, supervised the research. The faculty-appointed external examiner of the dissertation was Professor Daniel J Rixen from the Faculty of Mechanical, Maritime and Materials Engineering at Delft University of Technology in the Netherlands. The title of the dissertation is "Identification and synthesis of components for vibration transfer and path analysis".

Structure-borne vibrations and sound (SBV&S) are generated by the contact between wheel and rail and transmitted via the bogie structure into the car body. The aim of the VB7 project was to develop and investigate system identification methods and models to allow for analysis, prediction and reduction of SBV&S through a bogie. The focus has been on semi-physical modelling of the bogie suspension system (air cushions, dampers, etc).

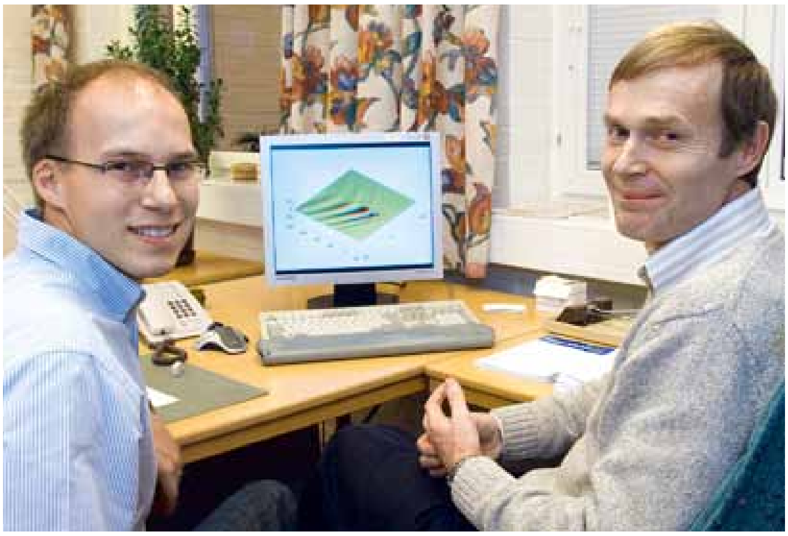
To validate a devised subsystem identification procedure, a small-scale physical experiment was designed and used in the laboratory of Chalmers Applied Mechanics. Examples of valuable a priori knowledge in the identification process, as based on physical insight, are (i) the reciprocity property for co-located and co-oriented pairs of excitation and response and (ii) the zero accelerance under static loading for structures without rigid-body modes. The theory for inclusion of such knowledge as constraints in state-space system identification has been developed. A passivity constraint must also be observed for the subsystem models considered here.

A procedure that is able to extract a substructure model from measurements on a larger dynamical system has been formulated. A method based on Kalman filter theory was developed, whereby problems of sensor placement and prediction of responses inaccessible for direct measurement are simultaneously approached. See also CHARMEC's Triennial Report for Stage 4.

PhD student Per Sjövall (centre; doctorate earned in November 2007) and his supervisors Professor Thomas Abrahamsson (left) and Professor Tomas McKelvey in the VB7 project inspecting a bogie at Gothenburg railway station. Photo taken in 2006

VB8. GROUND VIBRATIONS FROM RAILWAYS

Markvibrationer från järnväg
Bodenschwingungen von Eisenbahnen
Vibrations de sol causées par le chemin de fer



Dr Anders Karlström (left; doctorate earned in October 2006) and his supervisor Professor Anders Boström in project VB8. The screen displays the calculated vibrational field on the ground surface from a loaded wheelset travelling at supersonic speed relative to the Rayleigh wave speed along the ground surface. There is a trench on one side of the railway. Photo taken in 2006. For a photo of Thomas Abrahamsson, see page 33

Project VB8 was completed with Anders Karlström's successful defence in public of his doctoral dissertation in October 2006. Professor Anders Boström and Professor Thomas Abrahamsson from Chalmers Applied Mechanics were his supervisors. The faculty-appointed external examiner of the dissertation was Professor Andrei V Metrikine from the Faculty of Civil Engineering and Geosciences at Delft University of Technology in the Netherlands. The title of the dissertation is "On the modelling of train induced ground vibrations with analytical methods".

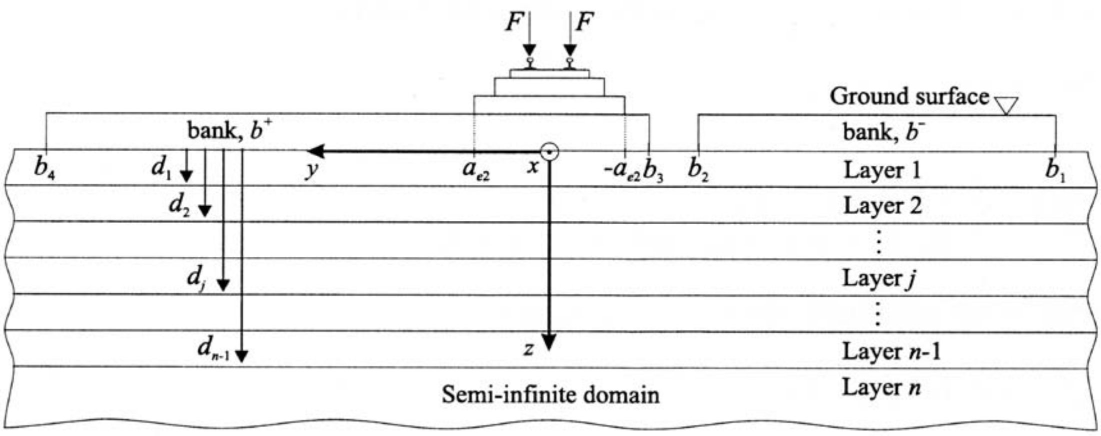
Refined models of the ground vibrations caused by train passages were established in project VB8 using simple analytical descriptions of sleepers and rails on a viscoelastic embankment resting on a layered viscoelastic ground. The models are linear and thus permit the use of advanced Fourier techniques to find solutions in the frequency domain. Groups of static forces (the weight of the train) travel on the beams modelling the rails. The forces may accelerate or decelerate. The model has been validated with good agreement against measurements performed on the West Coast Line at Ledsgård south of Gothenburg, see also projects VB5 and VB9.

Calculated results for supersonic train speeds showed that trenches along the railway have a positive effect on the attenuation of ground vibrations on the outer side of the trench. See also CHARMEC's Triennial Report for Stage 4. The present analytical model has been integrated with the numerical time-domain model in DIFF3D, see project TS8.

In a separate project led by Professor Anders Boström (and not financed through CHARMEC), the guest student Zhigang Cao earned his doctorate in 2011 and the below papers were written.

Zhigang Cao, Yuanqiang Cai, Anders Boström and Jianguo Zheng: Semi-analytical analysis of the isolation to moving-load induced ground vibrations by trenches on a poroelastic half-space, *Journal of Sound and Vibrations*, vol 331, no 4, 2012, pp 947-961

Zhigang Cao and Anders Boström: Dynamic response of a poroelastic half-space to accelerating or decelerating trains, *ibidem* (accepted for publication)



Cross-section of a general calculation model in project VB8 with one trench along the track, see also the screen display above

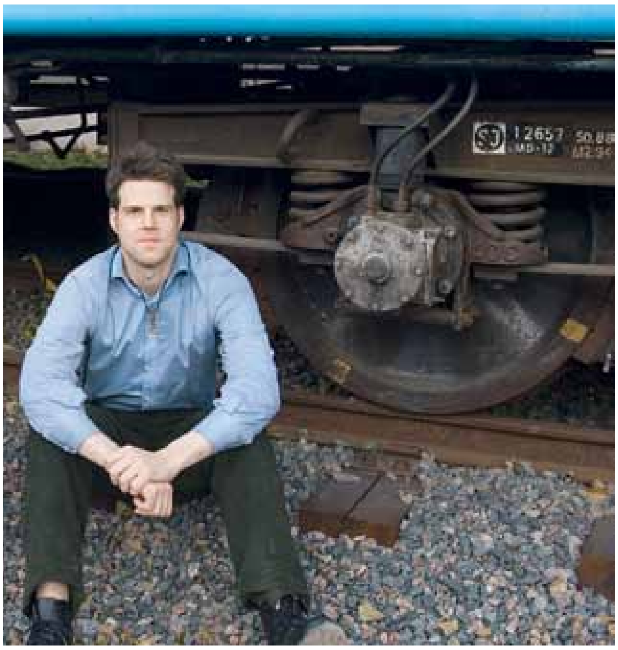
VB9. DYNAMICS OF RAILWAY SYSTEMS

Dynamik hos järnvägssystem
Dynamik von Eisenbahnsystemen
Dynamique des systèmes du chemin de fer

For a photo of Nils-Erik Wiberg and Torbjörn Ekevid, see page 32

The VB9 project was completed with Håkan Lane's successful defence in public of his doctoral dissertation in May 2007, when he also left Chalmers. Professor Nils-Erik Wiberg from Chalmers Applied Mechanics and Dr (now Professor) Torbjörn Ekevid from Växjö University (now Linnæus University) were his supervisors. The faculty-appointed external examiner of the dissertation was Professor Göran Sandberg from the Division of Structural Mechanics in the Faculty of Engineering at Lund University (LTH) in Sweden. The title of the dissertation is "Computational railway dynamics – integrated track-train-subgrade modeling and simulation".

The overall goal of project VB9 was to provide three-dimensional simulations of the entire railway system. Vehicle, track and underground were modelled as one compound system using the finite element (FE) method combined with rigid-body dynamics. Modern techniques for adaptive FE mesh generation were applied and parallel computing was employed in the numerical evaluations. Wave propagation in rails, embankment and surrounding ground were studied, in particular for combinations of high train speed and soft clay in the underground. Knowledge and skills gained in the previous project VB5 were utilized.



PhD student Håkan Lane (doctorate earned in May 2007) of project VB9. Photo taken in 2006

A moving mesh technique allowed for an analysis of three-dimensional motion with the train constantly at "the same" position in the mesh, e g, in the middle. A small mobile FE region can thus be used when a long stretch of track is studied. A tuned viscoelastic layer surrounding the FE grid reduces the amount of unwanted reflections from the boundaries of the FE model. Practical vibration countermeasures in the form of installed lime-cement columns were studied numerically. See also CHARMEC's Triennial Reports for Stages 4 and 5.

From projects VB10 and VB11 (Gothenburg tram on line 8)

VB10. EXTERNAL NOISE GENERATION FROM TRAINS

Extern bullergenerering från tåg
Externe Geräuscherzeugung durch Züge
Bruit extérieur généré par les trains

Project leaders and supervisors	Professor Wolfgang Kropp, Civil and Environmental Engineering/Division of Applied Acoustics, and Dr Anders Frid, Bombardier Transportation Sweden
Doctoral candidate	Ms Astrid Pieringer (from 2006-05-01; Lic Eng December 2008; PhD May 2011)
Period	2006-05-01 – 2011-05-31
Chalmers budget (excluding university basic resources)	Stage 4: kSEK 125 Stage 5: kSEK 2 550 Stage 6: kSEK 1 650
Industrial interests in-kind budget	Stage 4: – Stage 5: kSEK 200 Stage 6: kSEK 200 *(Bombardier Transportation)*

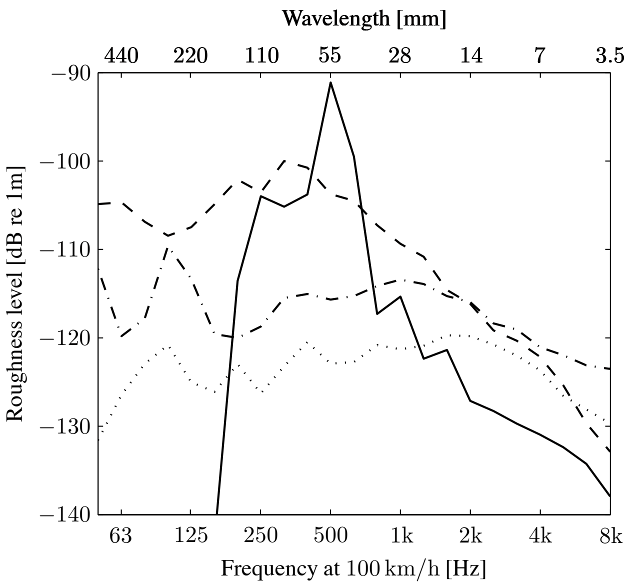
The project was partially financed by VINNOVA (through CHARMEC's budget). *For a photo of Astrid Pieringer, see page 38*

Traffic operators, infrastructure administrators, train manufacturers and society in general all have an interest in reducing external noise from railways. For moderate train speeds, the interaction between wheel and rail is the main source of noise emission. Rolling and impact noise are caused by the vertical interaction excited by roughness and discrete irregularities on the running surfaces of wheel and rail, whereas squeal noise, predominantly occurring on curves, is generated by the tangential interaction. Rolling noise and impact noise from wheel flats and rail joints are broadband phenomena involving a large range of frequencies in the audible range. Contrary to that, squeal noise is generally a tonal sound that dominates all other types of noise when it occurs. The overall aim of project VB10 was to develop suitable models for wheel–rail interaction and the ensuing noise generation. Projects VB10 and TS11 have been run in close co-operation.

Vertical interaction models have been formulated in the time-domain allowing the inclusion of non-linearities in the wheel–rail contact zone. Linear models of wheel and track are represented by Green's functions, which leads to a computationally efficient formulation. In a refined contact model, based on an influence-function method for an elastic half-space, the real three-dimensional (3D) wheel and rail geometries have been considered, with the roughness along several parallel lines being included. The model was applied to evaluate the contact filter effect, which consists in the attenuation of high-frequency excitation at the wheel–rail contact. The application of the 3D contact model was found to be preferable when the degree of correlation between roughness profiles across the width of the contact surfaces is low, see figures.

Frictional instabilities during curve negotiation have been investigated using a combined vertical and tangential interaction model. For both a constant friction law and a friction curve falling with the sliding velocity, stick/slip oscillations were observed which can be linked to noise-emitting vibration modes of the wheels. The imposed lateral creepage, the friction coefficient, and the lateral contact position were found to be key parameters for the occurrence of stick/slip and squeal. In particular, the conditions prevailing at the leading inner wheel of the bogie during curving (i e, under-radial position and contact towards the field side of the tread) were found to promote squeal.

Astrid Pieringer successfully defended her doctoral dissertation (see below) on 20 May 2011. The faculty-appointed external examiner of the dissertation was Dr Luis Baeza González from Universidad Politécnica de Valencia in Spain. Astrid Pieringer continues her research at Chalmers Applied Acoustics, see projects VB11 and VB12. The joint reference group for projects VB10 and TS11 consisted of members from Banverket /Trafikverket and SL Technology and from Bombardier Transportation in Germany (Siegen), Sweden and Switzerland. See also CHARMEC's Triennial Report for Stage 5.



Average roughness spectrum calculated from measurements along 7 parallel lines: —— corrugated rail, – – – wheel with cast-iron block brakes, – · – wheel 1 with sinter block brakes, and · · · wheel 2 with sinter block brakes

Astrid Pieringer and Wolfgang Kropp: A time-domain model for high-frequency wheel/rail interaction including tangential friction, *Proceedings 10th French Congress of Acoustics (CFA10 / 10ème Congrès Français d´Acoustique)*, Lyon (France) April 2010 (documented on CD)

Astrid Pieringer and Wolfgang Kropp: Generation of curve squeal, *16th Nordic Seminar on Railway Technology,* Nynäshamn (Sweden) September 2010, 1+56 pp (Summary and PowerPoint presentation. Documented on CD)

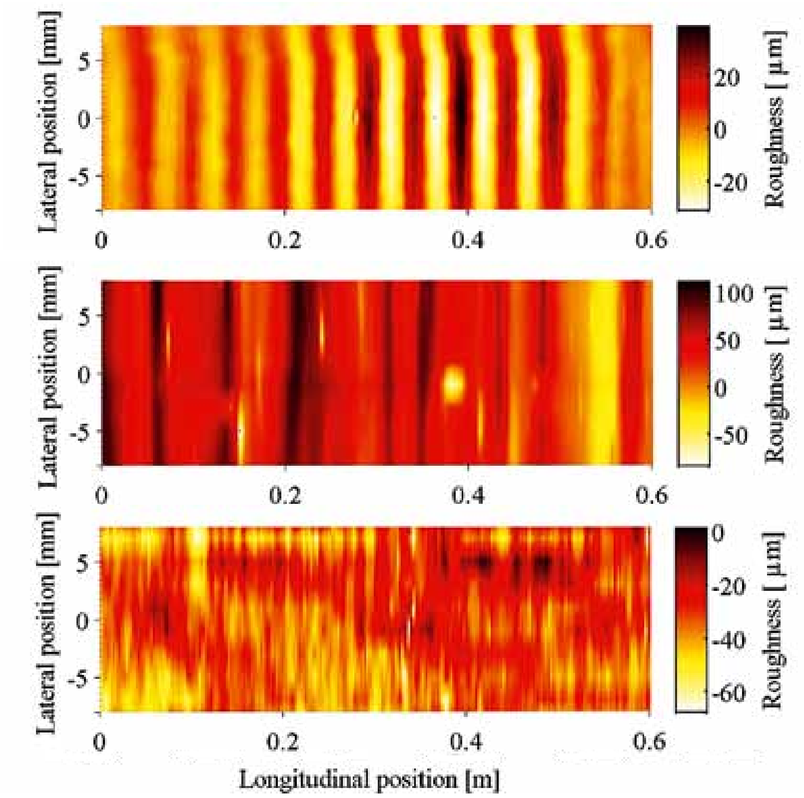
Astrid Pieringer and Wolfgang Kropp: A time-domain model for coupled vertical and tangential wheel/rail interaction – a contribution to the modelling of curve squeal, *Proceedings 10th International Workshop on Railway Noise (IWRN10)*, Nagahama (Japan) October 2010, pp 211-219 – Also in Notes on Numerical Fluid Mechanics and Multidisciplinary Design, vol 118, 2012, pp 221-229

Astrid Pieringer: Time-domain modelling of high-frequency wheel/rail interaction, Doctoral Dissertation, *Chalmers Civil and Environmental Engineering,* Gothenburg May 2011, 202 pp (Summary and five appended papers)

Astrid Pieringer, Wolfgang Kropp and David Thompson: Investigation of the dynamic contact filter effect in vertical wheel/rail interaction using a 2D and a 3D non-Hertzian contact model, *Wear,* vol 271, nos 1-2, 2011, pp 328-338

Astrid Pieringer, Wolfgang Kropp and Jens Nielsen: The influence of contact modelling on simulated wheel/rail interaction due to wheel flats, *Proceedings 9th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2012)*, Chengdu (China) August 2012, pp 406-415

Peter Torstensson, Astrid Pieringer and Jens Nielsen: Simulation of rail roughness growth on small radius curves using a non-Hertzian and non-steady wheel–rail contact model, *ibidem* Chengdu (China) August 2012, pp 223-230 (also listed under project TS11)



Three examples of measured roughness profiles in project VB10. From top to bottom: corrugated rail, wheel with cast-iron block brakes, and wheel with sinter block brakes

Vibrations and noise – Vibrationer och buller (VB) – Schwingungen und Geräusche – Vibrations et bruit

VB12. HIGH-FREQUENCY WHEEL–RAIL INTERACTION

Samverkan tåg–spår vid höga frekvenser
Wechselwirkung von Rad und Schiene bei hohen Frequenzen
Interaction roue–rail à hautes fréquences

Dr Astrid Pieringer at the Division of Applied Acoustics, Department of Civil and Environmental Engineering, runs this new two-year project together with Professor Wolfgang Kropp. It is funded partly by the Department and partly by the University as a so-called post-doctoral project under the Transport Area of Advance, see page 127. The work in the parallel doctoral project VB11 is being supported.

VB11. ABATEMENT OF CURVE SQUEAL NOISE FROM TRAINS

Reduktion av kurvskrikljud från tåg
Verminderung des Quitschens von Zûgen in Kurven
Réduction du grincement ferroviaire dans les courbes

Project leaders and supervisors	Professor Wolfgang Kropp and Dr Astrid Pieringer, Civil and Environmental Engineering/ Division of Applied Acoustics
Doctoral candidate	Mr Ragnar Vidarsson, MSc (2011-01-15 – 2011-06-30) Mr Ivan Zenzerovic, MSc (from 2012-06-01)
Period	2011-01-01 – 2012-06-30 (– 2017-05-31)
Chalmers budget (excluding university basic resources)	Stage 6: kSEK 1200 Stage 7: kSEK 2775
Industrial interests in-kind budget	Stage 6: kSEK 200 Stage 7: kSEK 200 *(Bombardier Transportation)*

From the left: Dr Astrid Pieringer, Professor Wolfgang Kropp and PhD student Ivan Zenzerovic from projects VB10 and VB11

Curve squeal is a highly disturbing tonal sound generated by railway cars, metros and trams when they negotiate a sharp curve. For curves with a radius of 200 m and below, curve squeal noise is common. In addition, such tight curves are situated mainly in urban areas where many people live close to the tracks, see photo on page 35. The noise is also a comfort issue for the passengers inside the vehicles.

Curve squeal noise is commonly attributed to self-excited vibrations of the railway wheel, which are induced either by stick/slip behaviour due to lateral creepage of the wheel tyre on the top of the rail or by contact on the wheel flange. Practical solutions to reduce the noise have been wheel damping and friction modifiers. However, it is desirable to gain a fundamental understanding of the mechanisms and causes of the squeal in order to find, if possible, appropriate vehicle and track designs to avoid or abate the generation of squeal noise. It should then be possible to predict not only the likelihood of noise but also its amplitude.

Project VB11 will be divided into four parts: (i) a further extension of the time-domain model developed in project VB10, (ii) an experimental validation of the model, (iii) an extensive study to identify the essential parameters (and their complex interaction) responsible for curve squeal, and (iv) an investigation of the potential to reduce curve squeal by design changes to track and wheel. Like project VB10, this project is also being run in co-operation with project TS11.

A measurement campaign on the SL line at Alvik – Stora Mossen in Stockholm has been run, and included measurements of both noise and vibration (vertical and lateral accelerations of the inner rail on a curve). The average speed of the accelerating trains was in the order of 20 km/h. The maxima in the spectrograms were compared with the frequencies of the wheel's axial eigenmodes, which are often the cause of the squealing, and in certain cases a good agreement was found. Acceleration signals with a strong saw-tooth shape were observed, possibly indicating stick/slip or flange climbing.

As part of the preparatory work for project VB11, the model for the prediction of squeal noise developed in project VB10 was extended so that it now contains the whole chain from time-domain calculation of contact forces between wheel and rail, over wheel vibration, to radiated sound from the wheel. A Boundary Element Model (BEM) of the wheel has also been set up and tested with an in-house BEM code. This model was found to be computationally very costly. However, this can be compensated for by an approach where transfer functions from point forces on the wheel (radial and tangential) to the complex sound pressure at reference points in the field are precalculated. Based on these transfer functions, the sound field radiated from a vibrating wheel can be simulated very efficiently.

The reference group for project VB11 has members from Bombardier Transportation (in Germany, Sweden and Switzerland), Interfleet Technology, SL and Trafikverket. The research plan for the project is dated 2010-05-15. The work has been delayed by the resignation of the original doctoral candidate and the recruitment of his successor.

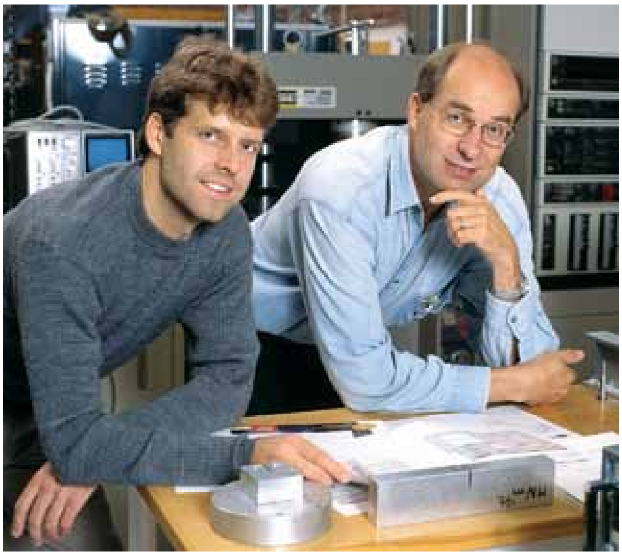
MU1. MECHANICAL PROPERTIES OF BALLAST

Ballastens mekaniska egenskaper
Mechanische Eigenschaften des Schotters
Propriétés mécaniques du ballast

The mechanical properties of ballast determine its ability to distribute the load carried down from the sleepers to the ground in such a way as to prevent detrimental deformations of the track. The MU1 project aimed to set up a constitutive model for the ballast mass, which in terms of continuum mechanics describes the relationship between stresses and deformations in a representative volume element (RVE) in an essentially arbitrary triaxial condition.

Constitutive models have been developed for both monotonic and repeated loading, making it possible to study the behaviour of the ballast mass when it is first rolled over and also when it is subject to long-term effects, such as subsidence and conditioned elasticity properties after being rolled over many times. Calibrations have been performed against laboratory experiments with ballast in triaxial cells.

Professor Kenneth Runesson led project MU1. After gaining his licentiate degree in January 1999, the doctoral candidate Lars Jacobsson left Chalmers for employment at SP Technical Research Institute of Sweden in Borås. His constitutive ballast model has been applied in the SP7 project reported below.



PhD student Lars Jacobsson (left; licentiate gained in January 1999) and his supervisor Professor Kenneth Runesson in project MU1. Photo taken in the laboratory of Chalmers Solid Mechanics in 2000

The title of the licentiate thesis is "A plasticity model for cohesionless material with emphasis on railway ballast". Professor Kennet Axelsson of LTU (Luleå Technical University) Soil Mechanics and Foundation Engineering introduced the discussion at the licentiate seminar. See also CHARMEC's Biennial and Triennial Reports for Stages 1, 2 and 3.

MU2. NEW MATERIALS IN WHEELS AND RAILS

Nya material i hjul och räler
Neue Werkstoffe in Rädern und Schienen
Nouveaux matériaux pour roues et rails

The MU2 project was completed with Johan Ahlström's successful defence in public of his doctoral dissertation in March 2001. Professor Birger Karlsson of Chalmers Engineering Metals (now Materials and Manufacturing Technology) supervised the research. The title of the dissertation is "Thermal and mechanical behaviour of railway wheel steel". The faculty-appointed external examiner of the dissertation was Professor Ian Hutchings from the Department of Materials Science and Metallurgy at the University of Cambridge, UK.

In co-operation with the wheelset manufacturer Lucchini Sweden (formerly Adtranz Wheelset) candidates for improved material quality were found based on extensive testing of specimens from different castings with different microalloying elements and different forging procedures and heat treatments up to the finished railway wheel. The fatigue behaviour and fracture toughness were studied. Models of phase transformations in a wheel during sliding contact with the rail were also investigated. See also CHARMEC's Triennial Reports for Stages 2 and 3.

Johan Ahlström has been employed in his department at Chalmers since April 2001 (now Senior Lecturer in Materials and Manufacturing Technology) and involved in the CHARMEC projects MU13, MU15, MU16, MU23, MU24 and EU10. He was awarded the academic degree of Docent in March 2010, see page 106.

For a photo of Johan Ahlström and Birger Karlsson, see page 49.

MU3. MARTENSITE FORMATION AND DAMAGE AROUND RAILWAY WHEEL FLATS

Martensitbildning och skadeutveckling kring hjulplattor
Martensitbildung und Beschädigung an Flachstellen
Formation de martensite et dommage autour des plats de roue

The MU3 project was completed with Johan Jergéus' successful defence in public of his doctoral dissertation in January 1998, after which he left Chalmers. The title of his dissertation is "Railway wheel flats – martensite formation, residual stresses, and crack propagation". The faculty-appointed external examiner of the dissertation was Professor Lennart Karlsson from the Department of Computer Aided Design at Luleå Technical University, Sweden. Professor Roger Lundén together with Professor Bengt Åkesson from Chalmers Solid Mechanics (now Applied Mechanics) supervised the research in project MU3.

A numerical model for the prediction of martensite formation under and around a wheel flat was developed. The model was calibrated against the approximately 240 wheel flats that were created under controlled conditions in the field trials at Silinge (near Flen west of Stockholm) in September 1996. A constitutive model was developed for the calculation of stresses in a material undergoing phase transformations. Transformation plasticity and plastic hardening memory loss during phase transformations were studied. The models were implemented in a commercial finite element (FE) code. New and better guidelines were proposed for the turning of wheels with a flat. See also CHARMEC's Biennial and Triennial Reports for Stages 1, 2 and 3.

PhD student Johan Jergéus (doctorate earned in January 1998) in project MU3. Photo taken in 1997. For a photo of Professor Roger Lundén, see page 61

MU4. PREDICTION OF LIFETIME OF RAILWAY WHEELS

Prediktering av livslängd hos järnvägshjul
Vorhersage der Lebensdauer von Eisenbahnrädern
Prédiction de la durée de vie des roues ferroviaires

The MU4 project was completed with Anders Ekberg's successful defence in public of his doctoral dissertation in April 2000 and his finalizing work up to June 2000. The title of the dissertation is "Rolling contact fatigue of railway wheels – towards tread life prediction through numerical modelling considering material imperfections, probabilistic loading and operational data". The faculty-appointed external examiner of the dissertation was Professor Michael W Brown from the Department of Mechanical Engineering at the University of Sheffield, UK. Professor Roger Lundén of Chalmers Solid Mechanics (now Applied Mechanics) supervised Anders Ekberg's research.

An important outcome of the MU4 project was the computer program WLIFE (Wheel Life) for estimation of the fatigue life of the rim of forged wheels in operation. WLIFE is based on the results of numerical simulations and laboratory and field experiments. The Dang Van equivalent-stress criterion is applied in the calculation of fatigue damage of a material volume in a multi-axial stress field with rotating principal directions. Statistical simulations, through use of a neural network, supplement WLIFE and speed up the computer runs. It was found that rolling contact fatigue of railway wheels is mainly related to the combination of peak loads (overloads) and a local decrease (because of local defects) in the fatigue resistance. See also CHARMEC's Biennial and Triennial Reports for Stages 1, 2 and 3 and the following projects MU9, MU10, MU19, MU20, MU21, MU22 and MU27 with continued research in the same area.

Anders Ekberg has been employed as senior researcher at Chalmers Solid Mechanics (now Applied Mechanics) since April 2000, where he has worked in close co-operation with Dr (now Docent) Elena Kabo. In August 2005, Anders Ekberg was appointed Docent, see page 106.

For a photo of Anders Ekberg and Roger Lundén, see page 61.

MU5. MECHANICAL PROPERTIES OF CONCRETE SLEEPERS

Mekaniska egenskaper hos betongsliprar
Mechanische Eigenschaften von Betonschwellen
Propriétés mécaniques des traverses en béton

The MU5 project was completed with Rikard Gustavson's (now Rikard Bolmsvik) successful defence in public of his doctoral dissertation in November 2002. Professor Kent Gylltoft of Chalmers Structural Engineering / Concrete Structures (now Civil and Environmental Engineering) supervised the research. The title of the dissertation is "Structural behaviour of concrete railway sleepers". The faculty-appointed external examiner of the dissertation was Dr Jens Jacob Jensen from SINTEF Civil and Environmental Engineering in Trondheim, Norway.

Extensive laboratory experiments with small specimens were carried out to clarify the bonding (adhesion and friction) between strands (tendons) and concrete in a prestressed sleeper. The three-dimensional bonding model for the prestressed strands, as developed in project MU5, has been incorporated into the general computer program DIANA for concrete structures.

There was close collaboration in project MU5 with the sleeper manufacturer Abetong. See also CHARMEC's Triennial Reports for Stages 2, 3 and 4. From December 2002 and onwards, Rikard Bolmsvik has been employed by Abetong AB in Växjö, Sweden. He has since then been involved at CHARMEC in projects TS10, SP9, SP12, SP16, SP17 and SP23 and also serves on the Board of CHARMEC from July 2008, see pages 8 and 123.

PhD student Rikard Gustavson (left; doctorate earned in November 2002) and his supervisor Professor Kent Gylltoft in project MU5. Photo taken in the laboratory of Chalmers Concrete Structures in 2000. For a new photo of Rikard Gustavson (Bolmsvik), see page 104

MU6. ROLLING CONTACT FATIGUE OF RAILS

Rullkontaktutmattning av järnvägsräl
Ermüdung von Schienen durch Rollkontakt
Fatigue des rails due au contact roulant

The MU6 project was completed with Jonas Ringsberg's successful defence in public of his doctoral dissertation in September 2000. The title of the dissertation is "Rolling contact fatigue of railway rails with emphasis on crack initiation". The faculty-appointed external examiner of the dissertation was Professor Roderick A Smith from the Department of Mechanical Engineering at the University of Sheffield, UK. Professor Lennart Josefson of Chalmers Solid Mechanics (now Applied Mechanics) supervised Jonas Ringsberg's research.

The rolling contact between railway wheels and rails often results in fatigue damage in the railhead. The MU6 project dealt with the cracks called head checks which, especially on curves, arise in a surface layer on the railhead. At high friction, gradually growing plastic deformation in shear occurs, so-called ratchetting. This phenomenon gradually leads to such an accumulation of damage that material fracture and cracks ensue. Work carried out in the MU6 project has made it possible to estimate the time that will elapse until head checks arise on a new or reground rail under a given traffic programme.

In April 2004, Jonas Ringsberg was appointed Docent, see page 106. He became a Senior Lecturer in the Department of Shipping and Marine Technology at Chalmers in November 2005 and a Professor in the same department in June 2009. See also CHARMEC's Triennial Reports for Stages 2, 3 and 4.

PhD student Jonas Ringsberg (left; doctorate earned in September 2000) and his supervisor Professor Lennart Josefson in project MU6. Photo taken in 2000. For a more recent photo of Lennart Josefson, see page 52

MU7. LASER TREATMENT OF WHEELS AND RAILS

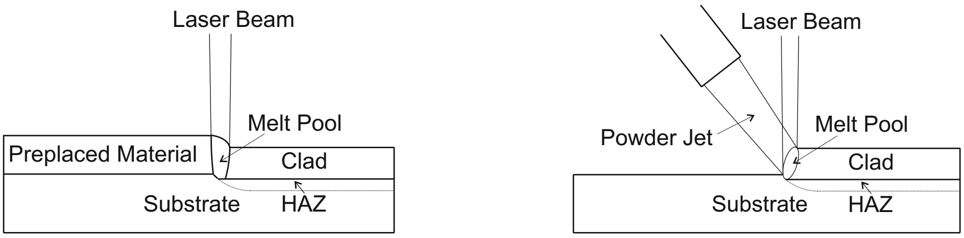
Laserbehandling av hjul och räl
Laserbehandlung von Rädern und Schienen
Traitement au laser des roues et des rails

The MU7 project was completed with Simon Niederhauser's successful defence in public of his doctoral dissertation in December 2005, when he also left Chalmers. The research was supervised by Professor Birger Karlsson from the Department of Materials and Manufacturing Technology. The title of the dissertation is "Laser cladded steel – microstructures and mechanical properties of relevance for railway applications". The faculty-appointed external examiner of the dissertation was Professor Andreas Mortensen from the Laboratory of Mechanical Metallurgy at Ecole Polytechnique Fédérale de Lausanne (EPFL) in Lausanne, Switzerland.

Project MU7 aimed to study opportunities for increasing the life and improving the functioning of railway wheels and rails onto which a surface layer (a coating) has been melted with the aid of laser technology and a powder flow. Such a process allows high-cost alloys to be cladded onto a cheaper substrate material, such as the railhead on curves. Tensile testing of rail materials with Co-Cr and Fe-Cr coatings demonstrated high yield strength and strong work hardening. Both coatings exhibited advantageous behaviour in low-cycle fatigue. Neither of the mechanical tests led to delamination of the clad material. See also CHARMEC's Triennial Reports for Stages 2, 3 and 4.

The project was run in collaboration with the company Duroc Rail in Luleå, Sweden. The reference group for project MU7 included members from Duroc companies in both Luleå and Umeå, Sweden.

PhD students Simon Niederhauser (centre; doctorate earned in December 2005) in project MU7 and Niklas Köppen (left; licentiate gained in November 2006) in project MU16 together with Dr Peter Sotkovszki of Chalmers Materials Science and Engineering (now Materials and Manufacturing Technology). Photo taken in 2003



Two-step cladding process (a) with the material being preplaced onto the substrate surface, and one-step cladding process (b) with powder being injected into the melt pool by an inert gas jet

MU8. BUTT-WELDING OF RAILS

Stumsvetsning av räl
Stumpfschweissen von Schienen
Soudure bout à bout de rails

The MU8 project was completed with Anders Skyttebol's successful defence in public of his doctoral dissertation in September 2004, when he also left Chalmers. The faculty-appointed external examiner of the dissertation was Professor Fredrick V Lawrence Jr from the Department of Civil and Environmental Engineering at the University of Illinois in Urbana-Champaign, USA. Professor Lennart Josefson together with Docent (now Professor) Jonas Ringsberg, both of Chalmers Applied Mechanics, supervised Anders Skyttebol's research. The title of the dissertation is "Continuous welded railway rails – residual stress analyses, fatigue assessments and experiments".

A detailed three-dimensional numerical simulation of the electrical, thermal and mechanical fields during flash butt-welding was performed in project MU8. Data for the thermal and electrical analyses were obtained both from the manufacturer of welding equipment and from Banverket's (now Trafikverket) shop at Sannahed. The constitutive model that was developed handles the recovery of hardening for a material that solidifies after being melted. Verifying experiments were carried out at Sannahed. The redistribution of welding residual stresses and the growth of fatigue cracks from defects in the rail weld was simulated. The time period for the growth of cracks from a size detectable by ultrasonics to a critical size was estimated. See also CHARMEC's Triennial Reports for Stages 3 and 4.

PhD student Anders Skyttebol (left; doctorate earned in September 2004) and his supervisor Professor Lennart Josefson in project MU8. Photo taken in 2003. For a more recent photo of Lennart Josefson, see page 52. For a photo of Jonas Ringsberg, see page 41

MU9. ROLLING CONTACT FATIGUE OF RAILWAY WHEELS

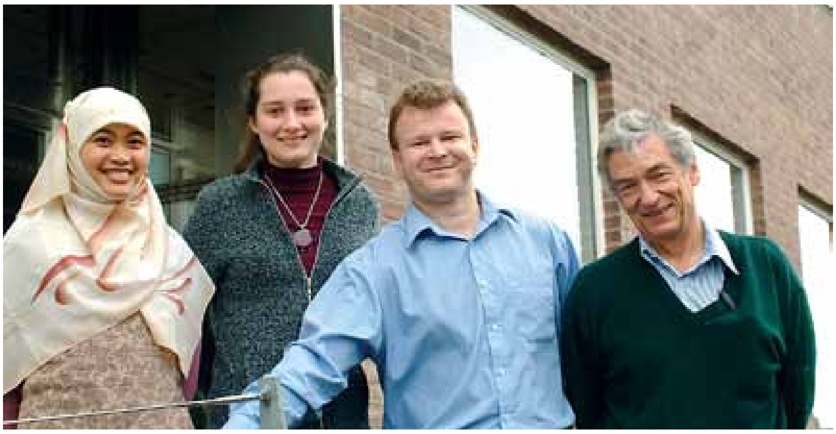
Rullkontaktutmattning av järnvägshjul
Ermüdung von Eisenbahnrädern durch Rollkontakt
Fatigue des roues ferroviaires due au contact roulant

Docent Anders Ekberg and Dr (now Docent) Elena Kabo (for photo, see page 61) led this senior research project, concluded in June 2006, with Professor Roger Lundén as their co-worker. The overall aim of project MU9 was to develop an "engineering" approach to rolling contact fatigue analysis while accounting for load magnitude, material quality, material anisotropy, material defects and manufacturing processes and also plastic deformations in operation. Several meetings were held with Bombardier Transportation, Deutsche Bahn, Duroc Rail, Lucchini Sweden, MTAB, Spoornet, Interfleet Technology and others for project discussions.

The computer program FIERCE (Fatigue Index Evaluator for Rolling Contact Environments) was developed and released as a stand-alone MATLAB code and has also been incorporated into commercial dynamic codes such as ADAMS/Rail and GENSYS. The FIERCE code evaluates the fatigue impact on the wheel rim based on the output from simulations of dynamic train–track interaction. Updated versions of FIERCE are being provided to Bombardier Transportation and other industrial partners. See also CHARMEC's Triennial Reports for Stages 3 and 4. The joint reference group for projects MU9 and MU10 included representatives from Bombardier Transportation Sweden and Interfleet Technology.

MU10. CRACK PROPAGATION IN RAILWAY WHEELS

Sprickfortplantning i järnvägshjul
Rissausbreitung in Eisenbahnrädern
Propagation de fissures dans les roues ferroviaires

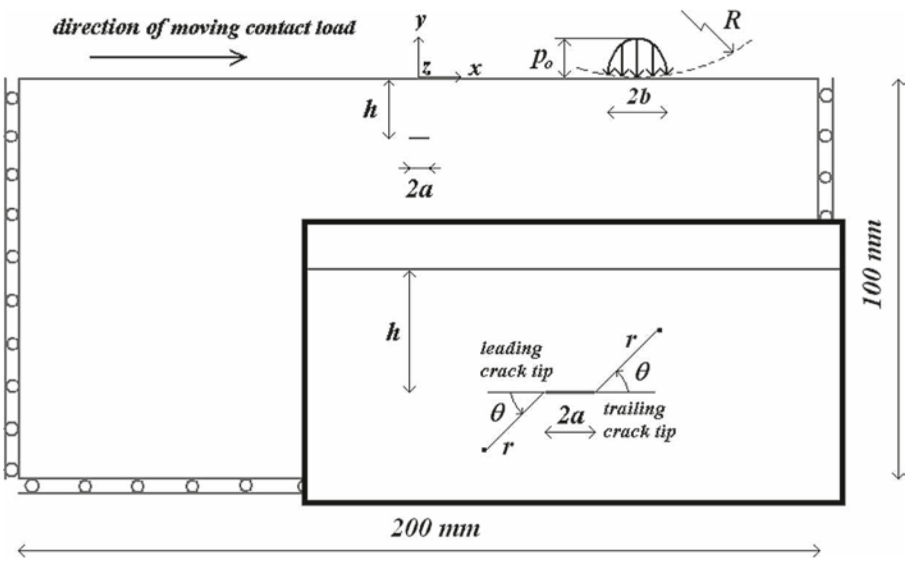


PhD student Eka Lansler (left; licentiate gained in January 2005) and her supervisors Professor Hans Andersson (right), Dr (now Docent) Elena Kabo and Docent Anders Ekberg in project MU10. Photo taken in 2003. For a new photo of Elena Kabo and Anders Ekberg, see page 50

The MU10 project was led by Professor Hans Andersson, Dr (now Docent) Elena Kabo and Docent Anders Ekberg. The doctoral candidate Eka Lanser left Chalmers after gaining her licentiate degree in January 2005 and a revised research plan was adopted. The title of Eka Lansler's thesis is "Subsurface rolling contact fatigue cracks in railway wheels – elastoplastic deformations and mechanisms of propagation". The discussion at the licentiate seminar was introduced by Professor Ulf Stigh from the University of Skövde, Sweden.

The aim of project MU10 was to establish suitable crack growth and fracture models for railway wheels. In particular, cracks initiated below the tread surface were studied, bearing in mind that such cracks grow in a multiaxial and essentially compressive stress field with rotating principal directions and that both elastic and elastoplastic material behaviour should be considered. It was found that the influence on crack propagation by operationally induced residual stresses and by plastic deformations during a load passage (a wheel revolution) is small.

In the continuation of the project, the influence of rail corrugation and wheel out-of-roundness on subsurface initiated rolling contact fatigue has been studied. For high-speed trains, it was found that increased peak contact force magnitudes (as opposed to poor contact geometry) is the main reason behind increased fatigue impact. The joint reference group for projects MU9 and MU10 included representatives from Bombardier Transportation Sweden and Interfleet Technology. See also CHARMEC's Triennial Reports for Stages 3 and 4.



Two-dimensional representation of part of a railway wheel with a crack of length 2*a* at depth *h* below the running surface. For different material responses, a Fatigue Parameter *FP* for the material in front of the trailing crack tip was evaluated in project MU10

MU11. EARLY CRACK GROWTH IN RAILS

Tidig spricktillväxt i räls
Frühstadium der Rissausbreitung in Schienen
Début de la propagation de fissures dans les rails

The aim of project MU11 was to develop numerical models for simulating and predicting the growth of surface cracks (head checks) once they have been initiated on the railhead. Professor Lennart Josefson, Dr (now Professor) Jonas Ringsberg and Professor Kenneth Runesson led the project. After gaining his licentiate degree in June 2005, the doctoral candidate Anders Bergkvist left Chalmers. The title of his thesis is "On the crack driving force in elastic-plastic fracture mechanics with application to rolling contact fatigue in rails". The discussion at the licentiate seminar was introduced by Dr (now Professor) Erland Johnson from the SP Technical Research Institute of Sweden.

A parameterized two-dimensional finite element model with a surface crack and a rolling contact load was established. Wear was included to account for a reduction in the effective crack growth rate due to crack mouth truncation. Short surface-breaking cracks were found to grow by shear. The highest crack growth rate along the railhead surface is in the direction of the largest reversed shear strain range. An in-depth study of the concept of "material forces" (from which the crack-driving force can be computed) was pursued. Project MU17 can partially be seen as a continuation of project MU11. See also CHARMEC's Triennial Report for Stage 4.

PhD student Anders Bergkvist (left; licentiate gained in June 2005) and his supervisor Dr (now Professor) Jonas Ringsberg in project MU11. Photo taken in 2003. For photos of Professor Lennart Josefson and Professor Kenneth Runesson, see pages 43 and 47

MU12. CONTACT AND CRACK MECHANICS FOR RAILS

Kontakt- och sprickmekanik för räls
Kontakt- und Rissmechanik für Schienen
Mécanique de contact et de fissuration des rails

Dr Per Heintz (left; doctorate earned in September 2006) and his supervisor Professor Peter Hansbo in project MU12. Photo taken in 2006

The MU12 project was completed with Per Heintz's successful defence in public of his doctoral dissertation in September 2006, when he also left Chalmers. Professor Peter Hansbo from Chalmers Applied Mechanics supervised the research. The title of the dissertation is "Finite element procedures for the numerical simulation of crack propagation and bilateral contact". The faculty-appointed external examiner of the dissertation was Professor Paul Steinman from the Department of Mechanical and Process Engineering at Technische Universität Kaiserslautern, Germany. The project was partially financed by the Chalmers Finite Element Center.

Numerical finite element (FE) techniques were developed to predict when and how a predefined crack in a rail will grow under given loading conditions. Lagrange multipliers (stabilized) were employed to enforce zero penetration and a balance of forces at the interface between wheel and rail. Adaptive FE calculations were carried out, applying so-called Eshelby mechanics (with material forces which are energy-conjugated to the propagation of defects in the material) as the starting point. The cracks studied can propagate through the individual finite elements.

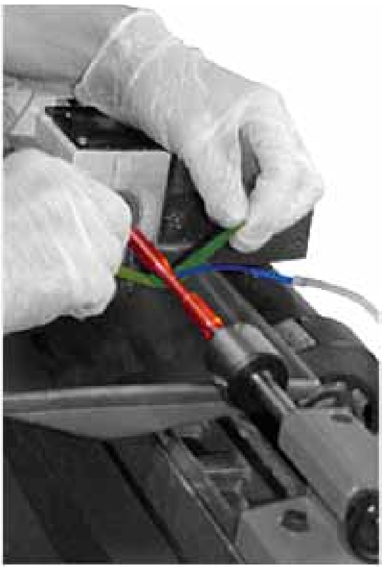
A set of Fortran module packages, written in Fortran 90/95, has been successfully compiled in both Windows and Linux operating systems. It is possible to import meshes and export results from and to the codes ABAQUS and LS-DYNA. See also CHARMEC's Triennial Reports for Stages 3 and 4.

MU13. WHEEL AND RAIL MATERIALS AT LOW TEMPERATURES

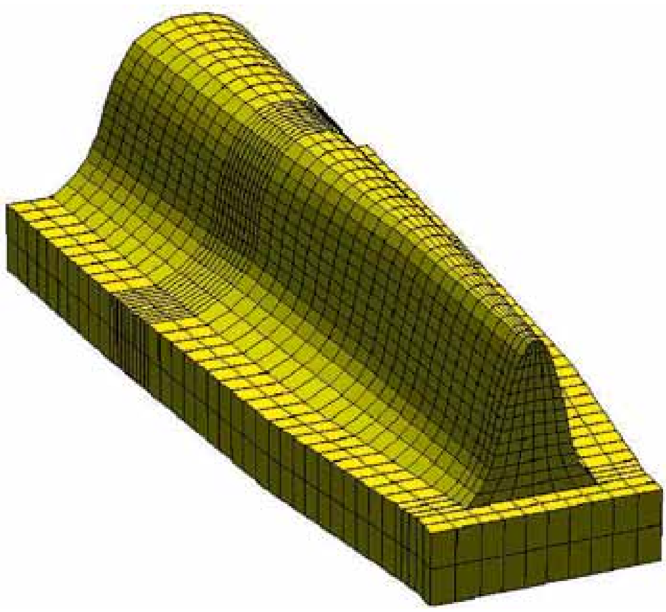
Hjul- och rälmaterial vid låga temperaturer
Werkstoffe für Räder und Schienen bei niedrigen Temperaturen
Matériaux des roues et rails aux basses températures

The researchers in this senior project, which concluded in June 2006, were Dr (now Docent) Johan Ahlström and Professor Birger Karlsson from Chalmers Materials and Manufacturing Technology (for photo, see page 49). The influence of operating temperatures down to -40°C on fatigue and fracture behaviour was studied. High loading rates in service at -40°C were simulated by slow rig testing at -60°C. The low-cycle fatigue behaviour at low temperatures was examined for the most promising of the wheel materials from the previous project MU2.

The joint reference group for projects MU13 and MU16 had members from Lucchini Sidermeccanica (Italy) and Bombardier Transportation Sweden. See also CHARMEC's Triennial Reports for Stages 3 and 4.



Preparation of a bar for fatigue testing in project MU13, starting with SiC grinding and finishing with diamond polishing. Rotating bar is shown in red and cooling water in blue



Turnout crossing and finite element model of crossing nose, as studied in project MU14

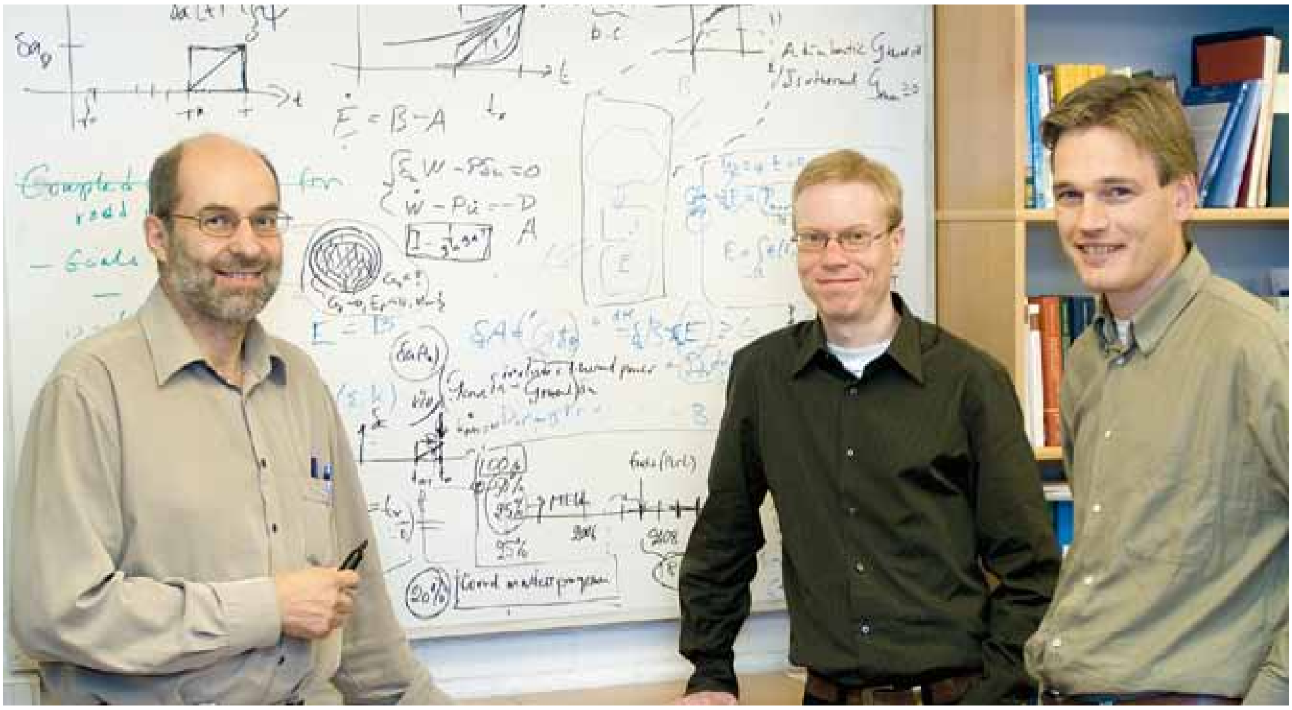
MU14. DAMAGE IN TRACK SWITCHES

Skador i spårväxlar
Schäden an Weichen
Détérioration des aiguillages

Docent (now Professor) Magnus Ekh and Professor Kenneth Runesson led project MU14. Its first part was concluded with Göran Johansson's successful defence in public of his doctoral dissertation in September 2006. The title of the dissertation is "On the modeling of large ratcheting strains and anisotropy in pearlitic steel". The faculty-appointed external examiner of the dissertation was Professor Bob Svendsen from the Faculty of Mechanical Engineering at the University of Dortmund, Germany. The project was then extended until June 2008 with Göran Johansson as part-time researcher.

The MU14 project aimed to provide a fundamental basis for the development of track switches (turnouts) which permit longer inspection intervals, have fewer faults at inspection, involve lower maintenance costs, and cause less disruption in rail traffic. One component under severe loading conditions is the crossing nose. Here mathematical modelling and simulation of large deformations and damage due to cyclic loading have been carried out. In particular, thermodynamically consistent constitutive material models for describing the large-strain response of polycrystalline metals have been developed, with an emphasis on the multi-axial ratchetting (i e, accumulation of plastic yielding) under cyclic loading. The model parameters have been identified against experimental data for a pearlitic steel.

MiniProf measurements of the dimensions of the crossing nose (made of manganese steel) have been made on a reference turnout UIC60-760-1:15 at Alingsås on the Western Main Line in Sweden. Parallel measurements have been performed in Stockholm (SL track) on a crossing nose made of the pearlitic rail steel 900A. The latter exhibited significant and continuing deformations during a few months' traffic while the former stayed almost unchanged. The research was carried out in collaboration with the turnout manufacturer VAE in Austria and the Department of Materials and Manufacturing Technology at Chalmers. See also CHARMEC's Triennial Reports for Stages 3 and 4. The TS7 and MU14 projects had a joint reference group, see under TS7.



Dr Göran Johansson (centre; doctorate earned in September 2006) and his supervisors Docent (now Professor) Magnus Ekh (right) and Professor Kenneth Runesson in project MU14. Photo taken in 2006

MU15. MICROSTRUCTURAL DEVELOPMENT DURING LASER COATING

Mikrostrukturens utveckling under laserbeläggning
Entwicklung des Mikrogefüges bei Laserbeschichtung
Développement de la microstructure pendant le revêtement par laser

The researchers in this senior project which concluded in June 2006, were Professor Birger Karlsson and Dr (now Docent) Johan Ahlström from Chalmers Materials and Manufacturing Technology (for photo, see page 49). Project MU15 was carried out in collaboration with the company Duroc Rail in Luleå (Sweden) and aimed to find optimum microstructures and properties of the coating (Co-Cr using a laser-based method) and the underlying heat-affected zone (HAZ) for maximizing the life-span of treated wheels and rails.

Some thirty specimens of the wheel material SURA B82 (corresponding to ER7) and five specimens of rail material UIC900A were hardened and ground followed by thermal exposure with the laser technique developed at Laserzentrum Leoben in Austria. A finite element model of the development of the temperature field during the laser treatment was established and numerical simulations were performed to enable extraction of more information from the tests.

The HAZ was found to develop with a thickness roughly the same as that of the clad itself. During the successive passes of the laser beam, the heating and cooling cycles resulted in austenitization and thereafter in the formation of either martensite or pearlite/bainite. The speed of the laser beam used during coating normally leads to martensite formation after the first pass. Subsequent passes result in tempering and considerable softening of the brittle martensite. Good control of geometry and passing speed is required to avoid untempered brittle martensite after a finished coating. Specific care must be taken at corners and at start and stop points of the running laser source. Compressive stresses built in during martensite formation were found to partly survive successive tempering steps. More astonishingly, such stresses were also preserved during later fatigue loading where they suppress cracking in the HAZ. See also CHARMEC's Triennial Reports for Stages 3 and 4.

MU16. ALTERNATIVE MATERIALS FOR WHEELS AND RAILS

Alternativa material för hjul och räler
Alternative Werkstoffe für Räder und Schienen
Matériaux alternatifs pour roues et rails

Project leaders and supervisors	Docent Johan Ahlström, Senior Lecturer, and Professor Birger Karlsson, Materials and Manufacturing Technology
Doctoral candidate	Mr Niklas Köppen (2003-10-01 – 2006-11-30; Lic Eng November 2006)
Period	2003-03-01 – 2010-12-31
Chalmers budget (excluding university basic resources)	Stage 3: kSEK 50 Stage 4: kSEK 2 000 Stage 5: kSEK 1 300 Stage 6: –
Industrial interests in-kind budget	Stage 3: – Stage 4: kSEK 100+500 *(Bombardier Transportation +Lucchini Sweden)* Stage 5: kSEK 400 *(voestalpine Bahnsysteme)* Stage 6: –

Higher demands on service life together with higher nominal loadings argue for better wheel and rail materials. Cleaner steels, systematic ultrasonic testing of manufactured components and better control of brake systems in wagons should all decrease the likelihood of accidents in railway traffic. In practice, however, all components suffer now and then from unexpected high loadings, internal material defects and damage by foreign objects, such as gravel indents etc. This calls for more damage-tolerant base materials.

The doctoral candidate in project MU16, Niklas Köppen, left Chalmers after gaining his Licentiate of Engineering on 10 November 2006. The title of his licentiate thesis is "Deformation behaviour of near fully pearlitic railway steels during monotonic and cyclic loading". After Niklas Köppen's resignation, the project has been run by the senior researchers and their Master's students. The joint reference group for projects MU16 and MU13 included members from Bombardier Transportation Sweden and Lucchini Sidermeccanica (Italy). VAE (Austria) was involved during the later phase of project MU16. See also CHARMEC's Triennial Reports for Stages 3, 4 and 5.

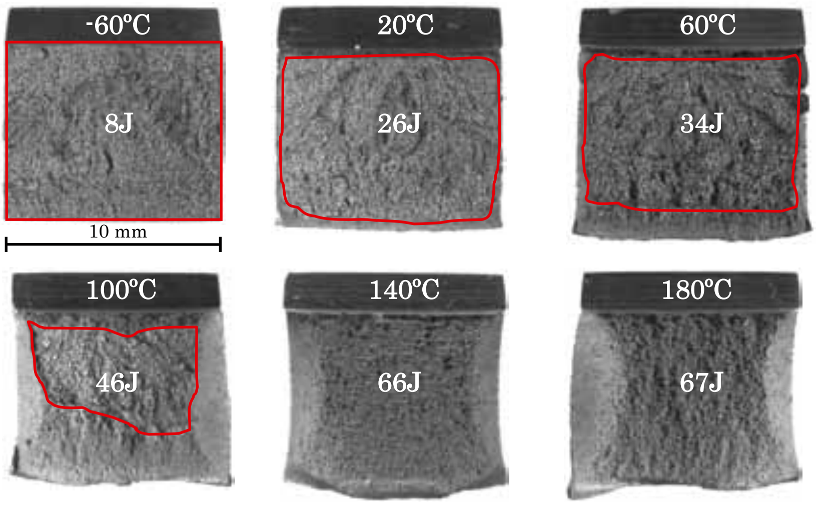
MU16. (cont'd)

PhD student Niklas Köppen (centre; licentiate gained in November 2006) and his supervisors Dr Johan Ahlström (left) and Professor Birger Karlsson in project MU16. Photo taken in 2006

During the first half of MU16, a batch of wheels with material specification UIC R8T from Lucchini Sidermeccanica in Italy was investigated with focus on low-cycle fatigue behaviour and monotonic deformation properties under different temperatures and strain rates. In the second half of MU16, three switch materials were studied with respect to monotonic and cyclic deformation properties: Mn13 (as-cast manganese steel), 51CrV4 (quenched and tempered steel), and Mn13 exposed to Explosion Deformation Hardening, the latter hereafter denoted Mn13EDH. The 51CrV4 material shows higher stress response and a similar number of cycles to failure at cyclic loading compared to typical rail material (R260 = UIC 900A), while the as-cast Mn13 shows lower stress response and a lower number of cycles to failure. On the other hand, the as-cast Mn13 steel shows a very large elongation to failure during monotonic deformation; this is due to the exceptional strain hardening capacity of this type of material.

The Mn13EDH exhibited different properties compared to as-cast Mn13. As expected, the monotonic yield strength is much higher for Mn13EDH, while the tensile strength is almost the same. This means that the strain hardening is almost exhausted during the hardening procedure, resulting in lower elongation to fracture. Because of its higher sensitivity to defects under tensile stress, the Mn13EDH has a considerably shorter and more scattered fatigue life than the as-cast Mn13. In railway applications, however, the peak tensile stress levels are much lower than in our low-cycle fatigue tests and this explains why the material can still perform well in revenue service.

Linda Norberg: Fatigue properties of austenitic Mn-steel hardened by explosion deformation – material used in highly stressed railway components, MSc Thesis 33/2010, *Chalmers Materials and Manufacturing Technology,* Gothenburg 2010, 40 pp

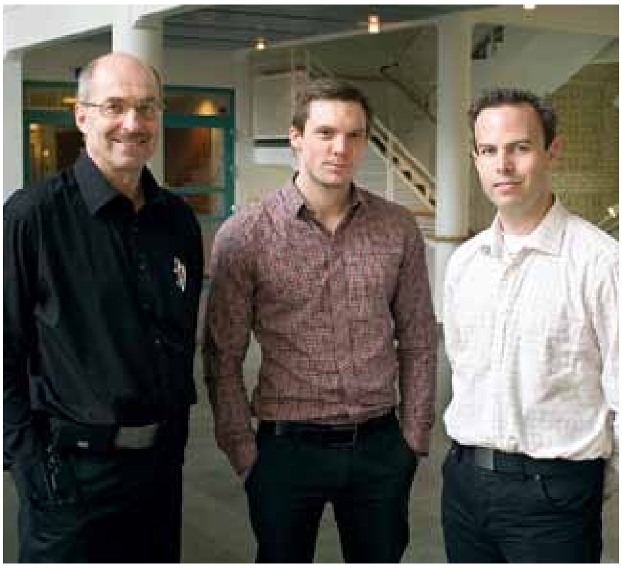


Charpy-V impact specimens of pearlitic railway wheel steel R8T as tested in project MU16. Fracture behaviour is seen to change from brittle to ductile with increasing temperature

MU17. ELASTOPLASTIC CRACK PROPAGATION IN RAILS

Elastoplastisk sprickfortplantning i räls
Elastoplastische Rissausbreitung in Schienen
Propagation élastoplastique de fissures dans les rails

Project leaders and supervisors	Docent Fredrik Larsson, Assistant Professor, Professor Kenneth Runesson and Professor Lennart Josefson, Applied Mechanics / Division of Material and Computational Mechanics
Doctoral candidate	Mr Johan Tillberg (from 2005-12-01; Lic Eng June 2008; PhD December 2010)
Period	2005-12-01 – 2010-12-30
Chalmers budget (excluding university basic resources)	Stage 4: kSEK 500 Stage 5: kSEK 2 350 Stage 6: kSEK 1 050
Industrial interests in-kind budget	Stage 4: kSEK 200 Stage 5: kSEK 300 Stage 6: kSEK 300 *(voestalpine Bahnsysteme)*



PhD student Johan Tillberg (middle; doctorate earned in December 2010) and his supervisors Professor Kenneth Runesson (left) and Docent Fredrik Larsson in project MU17. Photo taken in 2009. For a photo of Professor Lennart Josefson, see page 43

Project MU17 dealt with numerical simulation of crack propagation in rails in the context of rolling contact fatigue (RCF) and head check cracks, see photo. After reaching a depth of a few millimetre below the surface, these cracks may change their direction of propagation. In most cases, the cracks turn upwards into the rail surface. This leads to spalling, i e, small pieces of the surface material are detached. In some cases the cracks turn downwards into the rail, which can eventually cause complete rail failure.

An in-depth investigation has been conducted of models and methods in elastoplastic fracture mechanics in the presence of truly large plastic deformations. Such conditions are highly relevant for the early propagation of head checks in rails where several cracks interact in a complex fashion promoted by the rotating stress field during each single over-rolling of the wheels. The crack-driving force (generalized J-integral) is defined here through "material forces" (also called "configurational forces"), which are vectorial measures of the energy release rate due to a (virtual) variation of the position of the crack tip. Several parametric studies of geometric and material properties that affect the interaction of surface cracks have been carried out for loading situations that mimic an over-rolling wheel. The peak value of the J-integral during an over-rolling was found to decrease with decreasing crack interspacing, a phenomenon called crack shielding.

Johan Tillberg successfully defended his doctoral dissertation (see below) on 10 December 2010. The faculty-

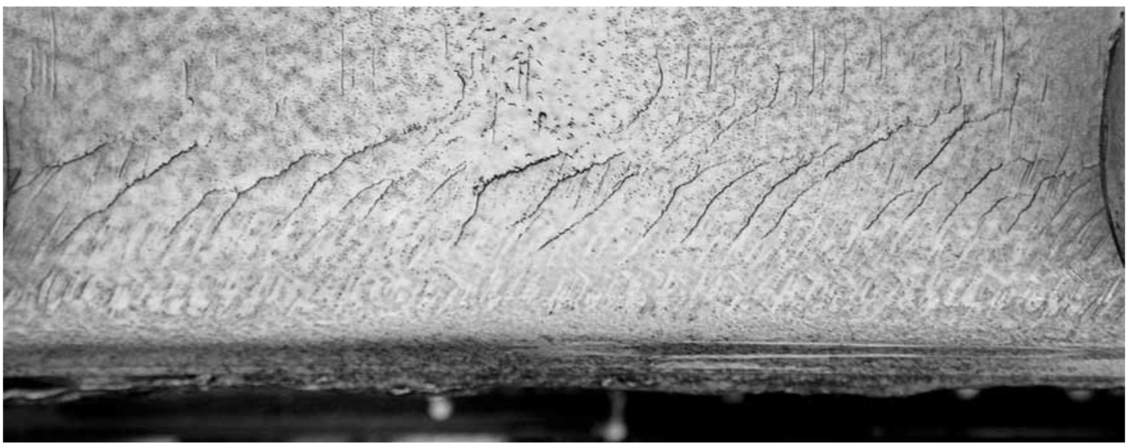
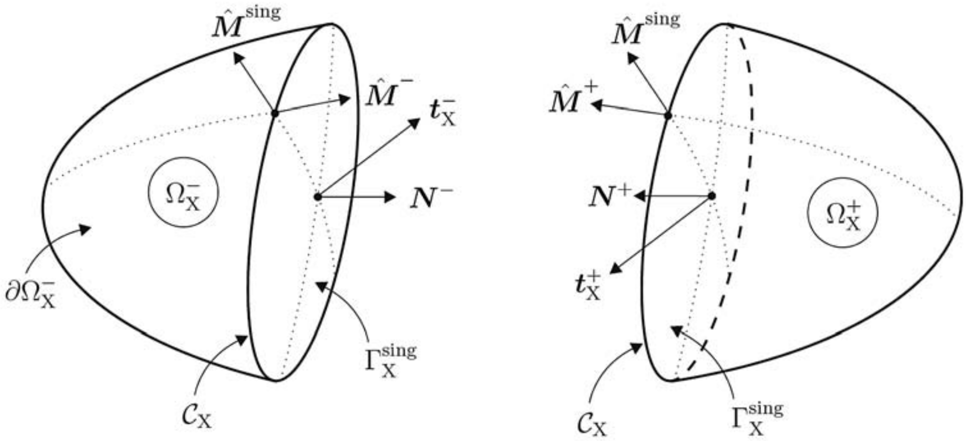


Photo of head checks on a railhead



Example of general model used in the study of configurational forces in project MU17

appointed external examiner of the dissertation was Professor Rolf Mahnken from the Faculty of Mechanical Engineering at the University of Paderborn in Germany. There has been close co-operation between projects MU17 and MU20. The CHARMEC-voestalpine meetings held twice a year, see page 114, played the role of reference group meetings for project MU17. Johan Tillberg has left Chalmers for a position at the consultancy Epsilon AB in Gothenburg. See also CHARMEC's Triennial Report for Stage 5.

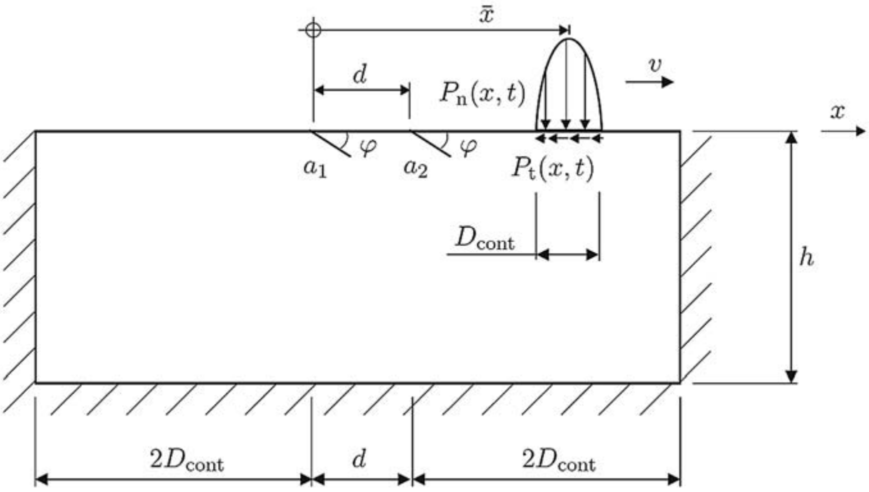
Kenneth Runesson, Fredrik Larsson and Paul Steinmann: On energetic changes due to configurational motion of standard continua, *International Journal of Solids and Structures,* vol 46, 2009, pp 1464-1475

Johan Tillberg, Fredrik Larsson and Kenneth Runesson: On the computation of the crack-driving force in elastic-plastic solids, *10th International Conference on Computational Plasticity (COMPLAS X)*, Barcelona (Spain) September 2009 (abstract documented on CD), 4 pp

Fredrik Larsson, Kenneth Runesson and Johan Tillberg: Configurational forces derived from the total variation of the rate of global dissipation, *Proceedings IUTAM Symposium on Progress in the Theory and Numerics of Configurational Mechanics,* Erlangen (Germany) October 2008, *IUTAM Bookseries,* vol 17, Springer 2009, pp 47-59

Johan Tillberg, Fredrik Larsson and Kenneth Runesson: On the role of material dissipation for the crack-driving force, *International Journal of Plasticity,* vol 26, no 7, 2010, pp 992-1012

Johan Tillberg: Elastic-plastic fracture mechanics – application to rolling contact fatigue in rails, Doctoral Dissertation, *Chalmers Applied Mechanics,* Gothenburg December 2010, 119 pp (Summary and five appended papers)



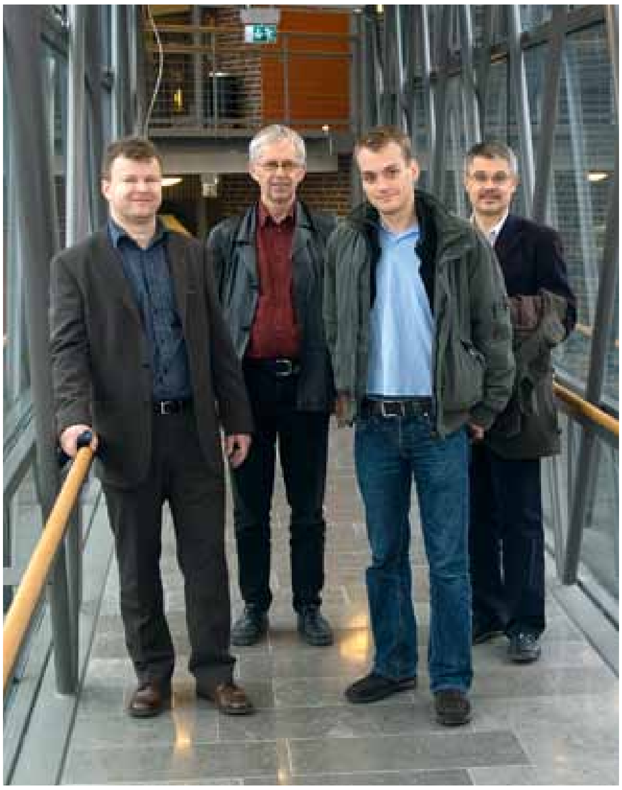
Two-dimensional plain strain model of a rail studied in project MU17. Crack angle φ, crack spacing d, crack lengths a_1, a_2, ..., normal contact stress $P_n(x,t)$, tangential contact stress $P_t(x,t)$, length D_{cont} of contact zone, speed v of load, and position $\bar{x}$ of load

MU18. WHEELS AND RAILS AT HIGH SPEEDS AND AXLE LOADS

Hjul och räler vid höga hastigheter och axellaster
Räder und Schienen bei hohen Geschwindigkeiten und Achslasten
Roues et rails à grande vitesse et à charge à l'essieu lourde

Project leader and supervisor	Docent Anders Ekberg, Applied Mechanics/ Division of Dynamics
Assistant supervisors	Professor Lennart Josefson and Professor Kenneth Runesson, Applied Mechanics, and Professor Jacques de Maré, Mathematical Sciences
Doctoral candidate	Mr Johan Sandström (from 2006-04-18; Lic Eng October 2008; PhD November 2011)
Period	2006-04-18 – 2011-12-31)
Chalmers budget (excluding university basic resources)	Stage 4: kSEK 375 Stage 5: kSEK 1750 Stage 6: kSEK 1000
Industrial interests in-kind budget	Stage 4: – Stage 5: kSEK 200+100+200 Stage 6: kSEK 200+100+200 *(Banverket/Trafikverket +Bombardier Transportation +Lucchini Sweden)*

The project was partially financed by VINNOVA (through CHARMEC's budget)



PhD student Johan Sandström (second from the right; doctorate earned in November 2011) in project MU18 together with his supervisors Docent Anders Ekberg (left), Professor Jacques de Maré (second from the left) and Professor Lennart Josefson. Photo taken in 2006

Increases in both maximum train speeds and maximum axle loads are being implemented in Sweden. This has raised a number of technical challenges, two of which are: (i) the number of potential passengers in high-speed operations is relatively low compared to the distances travelled, which calls for low-cost solutions accounting for the fact that high-speed trains today operate on existing tracks with mixed traffic, and (ii) heavy-haul operations must endure a harsh climate and mixed traffic and bear high labour costs, all of which call for reliable solutions that can be maintained with a lean organization. Also, Sweden's railway system consists of many single track lines and many stretches are operated close to peak capacity. Thus, if technical problems arise there will be a need to quickly identify the root causes and implement countermeasures. This calls for an understanding of damage mechanisms and a quantification of the gains provided by different countermeasures. The focus in project MU18 has been on defects and discontinuities in the wheel–rail system which affect the risk of fatigue and fracture of components such as wheels, rails and insulated joints. The present work has benefitted from several previous and parallel CHARMEC projects.

The initial study within the project concerned the probability of rail breaks under impact loads on the Iron Ore Line in northern Sweden, which was selected because of its well-defined operational characteristics. The influence of wheel flat impacts at random positions on the growth of existing rail cracks and on subsequent rail breaks was investigated. To account for the high-frequency excitation due to impacts, the in-house code DIFF was employed for the analysis of dynamic train–track interaction. Stress intensity factors for gauge corner cracks were derived from finite element (FE) simulations. Added loading due to restricted thermal contraction of all-welded rails at low temperatures was included, see sketch. Crack growth rates have also been quantified. The results indicate that wheel flats increase the risk of rail breaks and decrease the size of a crack that may cause final fracture. However, wheel flats have only a limited influence on the growth rate of fatigue cracks.

Numerical simulations have also been performed to study plastic deformation and fatigue impact at an insulated rail joint. The simulations feature a sophisticated constitutive model able to model multi-axial ratchetting which is indicated as the main damage mechanism. Effects are quantified for increased vertical and longitudinal load magnitudes and insulating gap widths. High longitudinal loading at traction and braking (under high friction) was found to be severely deteriorating for the rail material. In parallel, the degradation of insulated joints under revenue operations has been continuously followed in-field at Falkenberg on the West Coast Line in Sweden.

To evaluate the risk of subsurface cracking in a wheel, the Dang Van equivalent stress under Hertzian contacts has been employed. Subsurface initiated rolling contact fatigue cracks start in the vicinity of material defects. As these exist randomly in the wheel material, fatigue will appear randomly under otherwise constant conditions. Corrugation of the running surfaces will further add to the randomness. A combination of statistical methods, contact mechanics and fatigue analysis was employed in the present project. The statistical properties of the material defects, the contact geometry and contact load, and the output from a full train–track simulation, were taken as input. For the failure analysis, the damage accumulation under random amplitude loading was evaluated. The results show how a combination of rail corrugation and high train speeds has a significant impact on the probability of fatigue. A sensitivity analysis reveals a strong influence of both the fatigue strength and the material defect distribution.

The MU18 project was completed with Johan Sandström's successful defence in public of his doctoral dissertation (see below) on 14 November 2011. The faculty-appointed external examiner of the dissertation was Professor Stefano Beretta from the Department of Mechanics at Politecnico di Milano in Italy. The joint reference group for projects MU18, MU21, MU22 and MU25 had members from Banverket/Trafikverket, Bombardier Transportation (Germany/Siegen and Sweden), Interfleet Technology, KTH and SweMaint. Johan Sandström has now taken up a position with the consultancy Epsilon AB in Gothenburg. See also CHARMEC's Triennial Report for Stage 5.

Johan Sandström: Sannolikhet materialdefektinitierad utmattning av järnvägshjul (Probability material-defect-initiated fatigue of railway wheels; in Swedish), *16th Nordic Seminar on Railway Technology,* Nynäshamn (Sweden) September 2010, 1+18 pp (Summary and PowerPoint presentation. Documented on CD)

Johan Sandström and Jacques de Maré: Probability of subsurface fatigue initiation in rolling contact, *Wear,* vol 271, nos 1-2, 2011, pp 143-147 (revised article from conference CM2009)

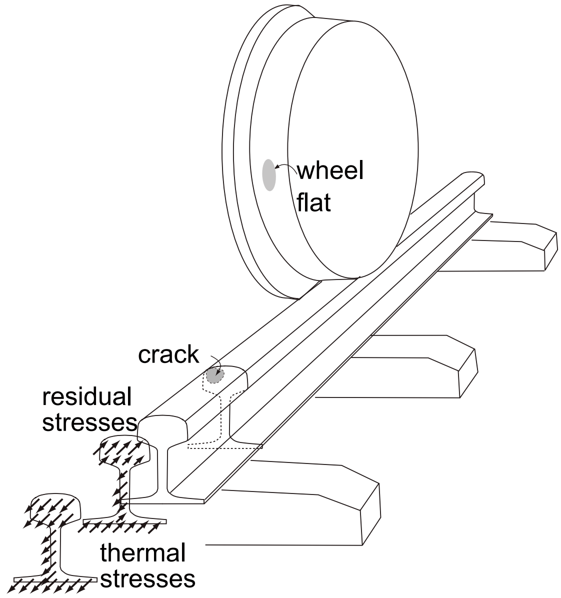
Johan Sandström: Wheels, rails and insulated joints – damage and failure probability at high speed and axle load, Doctoral Dissertation, *Chalmers Applied Mechanics,* Gothenburg November 2011, 92 pp (Summary and five appended papers)

Johan Sandström: Subsurface rolling contact fatigue damage of railway wheels – a probabilistic analysis, *International Journal of Fatigue,* vol 37, 2012, pp 146-152

Johan Sandström: Evaluation of Dang Van stress in Hertzian rolling contact, *Fatigue & Fracture of Engineering Materials & Structures* (accepted for publication)

Johan Sandström. Elena Kabo, Arne Nissen, Fredrik Jansson, Anders Ekberg and Roger Lundén: Deterioration of insulated rail joints – a three-year field study, *Proceedings 9th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2012)*, Chengdu (China) August 2012, pp 301-308

Head check crack propagating to full rail failure on Malmbanan (Iron Ore Line) in Northern Sweden

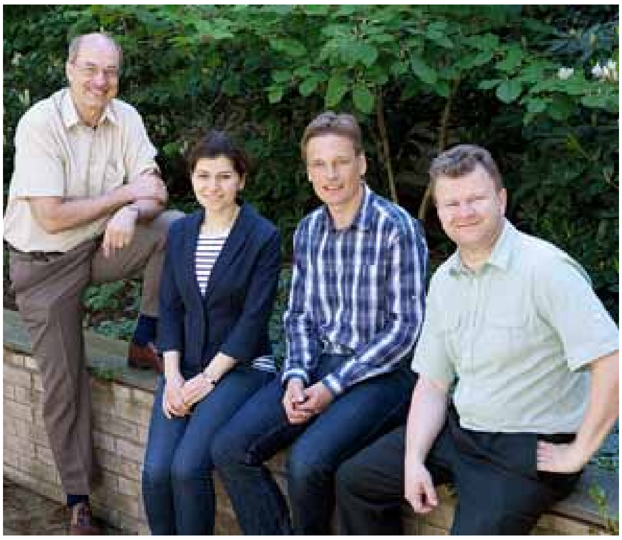


Sketch of out-of-round wheel passing a rail section with head check crack and tensile thermal stresses because of low temperature

MU19. MATERIAL ANISOTROPY AND RCF OF RAILS AND SWITCHES

Materialanisotropi och rullkontaktutmattning av räler och växlar
Materialanisotropie und Rollkontaktermüdung von Schienen und Weichen
Anisotropie des matériaux et fatigue sous charge roulante des rails et des aiguilles

Project leader and supervisor	Professor Magnus Ekh, Applied Mechanics / Division of Material and Computational Mechanics
Assistant supervisors	Professor Kenneth Runesson and Docent Anders Ekberg, Applied Mechanics
Doctoral candidate	Ms Nasim Larijani (from 2009-06-22; Lic Eng May 2012)
Period	2009-06-22 – 2014-06-30
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 100 Stage 6: kSEK 2550 Stage 7: kSEK 1860
Industrial interests in-kind budget	Stage 5: kSEK 100+50+100 Stage 5: kSEK 100+50+400 Stage 7: kSEK 100+50+200 *(Banverket/Trafikverket +SL +voestalpine Bahnsysteme)*



PhD student Nasim Larijani (licentiate gained in May 2012) and her supervisors Professor Magnus Ekh (second from the right), Professor Kenneth Runesson (left) and Docent Anders Ekberg

One of the main sources of damage to rails and switches involving rolling contact fatigue (RCF) is the large plastic deformations that accumulate in the surface layer of these components (from manufacturing, frictional rolling contact and wear/grinding). In components made of pearlitic carbon steel these deformations induce anisotropic mechanical properties. The objective of project MU19 is to investigate the effect of this anisotropy on the RCF properties of pearlitic steel components. The project draws on several previous CHARMEC projects, such as MU6, MU11, MU14 and MU17, and there has been close co-operation with ongoing work in projects MU20 and MU24.

In a first part of the present work, a material model for predicting large irreversible deformations in components made of pearlitic carbon steel has been established, based on the findings from project MU14. On the microscopic level, this steel is a two-phase material consisting of cementite lamellae embedded in a softer ferrite phase. Large plastic deformations lead to a re-orientation and alignment of the lamellae and this phenomenon is believed to explain the evolution of anisotropy. A macroscopic model formulated for large strains, which captures the re-orientation and its influence on the macroscopic yielding of the material, has therefore been proposed. The re-orientation leads to so-called distortional hardening of the yield surface.
In a second part of the present work, the influence of an anisotropic surface layer on the propagation of cracks in pearlitic rail steel has been investigated. Experimental results reported in the literature have shown significant effects of anisotropy on both fracture toughness and fatigue crack propagation rate in heavily deformed pearlitic structures. Thus, anisotropy should be taken into account when trying to predict the fatigue life of components subjected to large deformations. The alignment of the cementite lamellae also results in changes of the resistance against crack propagation in different directions.

Micrographs of the surface layer of pearlitic steel rails, tested on a full-scale test rig at voestalpine Schienen in Leoben (Austria), show a transition from a fully aligned microstructure (a high degree of anisotropy) at the surface to a randomly oriented lamellar structure (isotropy) a few millimetre below the surface of the railhead. Based on these observations, an anisotropic fracture surface model for capturing the anisotropic resistance against crack propagation and its dependence on the depth from the surface has been proposed. Simulations show that the characteristics of the surface layer have a substantial influence on the crack path.

Nasim Larijani presented her licentiate thesis (see below) at a seminar on 28 May 2012 where Docent Jonas Faleskog of KTH Solid Mechanics introduced the discussion. Project MU19 is continuously being presented and discussed during biannual workshops with participants from University of Leoben (Austria), voestalpine Schienen and CHARMEC, see page 114. The research plan of project MU19 is dated 2006-11-22.

Nasim Larijani, Magnus Ekh and Erik Lindfeldt: On the modeling of deformation induced anisotropy in pearlitic steel, *Proceedings 22nd Nordic Seminar on Computational Mechanics (NSCM-22)*, Aalborg (Denmark) October 2009, pp 55-57

Nasim Larijani: Modeling of deformation induced anisotropy in pearlitic steel, *16th Nordic Seminar on Railway Technology,* Nynäshamn (Sweden) September 2010, 1+18 pp (Summary and PowerPoint presentation. Documented on CD)

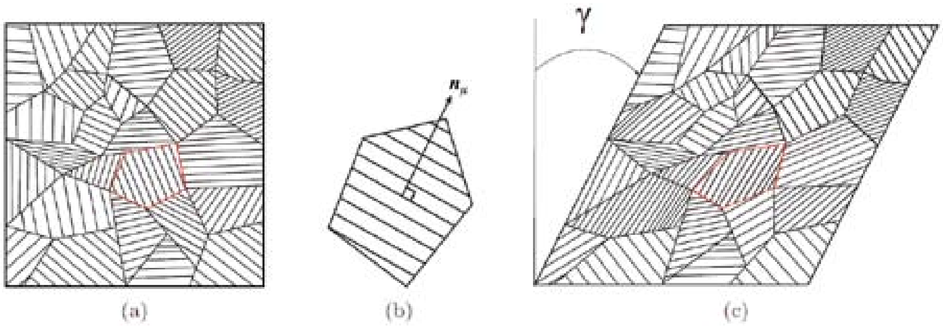
Nasim Larijani, Magnus Ekh, Göran Johansson and Erik Lindfeldt: On the modeling of deformation induced anisotropy of pearlitic steel, *Proceedings 23rd Nordic Seminar on Computational Mechanics (NSCM-23),* Stockholm (Sweden) October 2010, pp 153-156

Nasim Larijani and Magnus Ekh: Modeling of anisotropy evolution and cyclic behavior of pearlitic steel, *Book of Abstracts 2nd International Conference on Material Modeling (ICMM-2),* Paris (France) August 2011, p 323

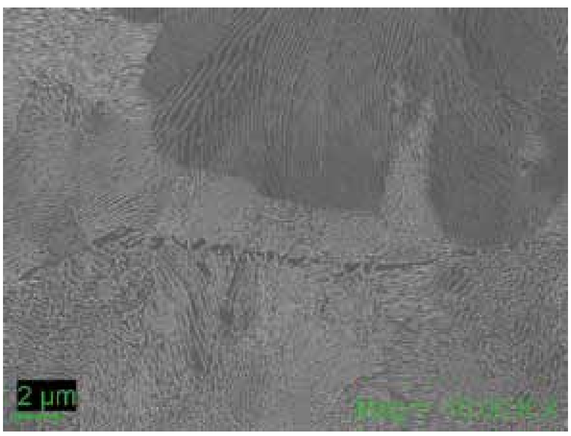
Nasim Larijani, Göran Johansson and Magnus Ekh: Hybrid micro-macromechanical modeling of anisotropy evolution in pearlitic steel (submitted for international publication)

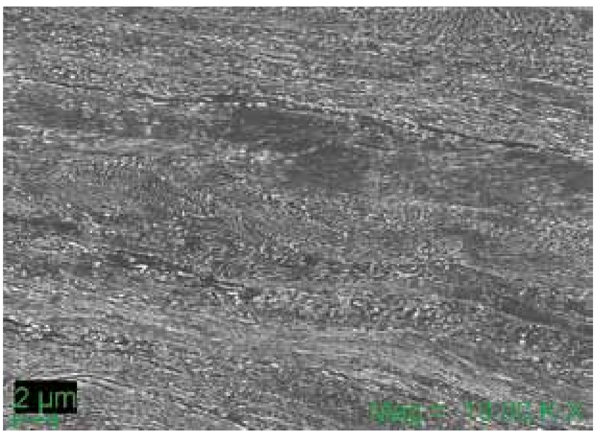
Nasim Larijani: On the modeling of anisotropy in pearlitic steel subjected to rolling contact fatigue, Licentiate Thesis, *Chalmers Applied Mechanics,* Gothenburg May 2012, 65 pp (Introduction and two appended papers)

Nasim Larijani, Jim Brouzoulis, Martin Schilke and Magnus Ekh: The effect of anisotropy on crack propagation in pearlitic rail steels, *Proceedings 9th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2012)*, Chengdu (China) August 2012, pp 432-441 (also listed under projects MU20 and MU24)



Sketches in project MU19 showing (a) a two-dimensional representative volume element (RVE) of an undeformed pearlitic structure, (b) a single colony with aligned cementite lamellae with normal direction, and (c) a two-dimensional RVE of a pearlitic structure deformed by pure shear





Scanning Electron Microscope (SEM) micrographs of pearlitic structure in surface layer of a used rail at a depth of 2 mm (left) and 100 μm (right) as studied in project MU19

MU20. WEAR IMPACT ON RCF OF RAILS

Nötningens inverkan på rullkontaktutmattning av räler
Einfluss des Verschleisses auf Rollkontaktermüdung von Schienen
Influence de l'usure sur fatigue sous charge roulante des rails

Project leader and supervisor	Professor Magnus Ekh, Applied Mechanics / Division of Material and Computational Mechanics
Assistant supervisors	Docent Fredrik Larsson and Docent Anders Ekberg, Applied Mechanics
Doctoral candidate	Mr Jim Brouzoulis (from 2007-12-01; Lic Eng May 2010)
Period	2007-12-01 – 2012-11-30
Chalmers budget (excluding university basic resources)	Stage 5: KSEK 1 300 Stage 6: KSEK 2 550 Stage 7: KSEK 300
Industrial interests in-kind budget	Stage 5: KSEK 100+50+100 Stage 6: KSEK 100+50+400 Stage 7: KSEK 50+25+100 *(Banverket/Trafikverket +SL +voestalpine Bahnsysteme)*

The deterioration of rails and wheels is an important issue in railway maintenance engineering. Rail damage manifests itself in different forms at the wheel–rail contact, such as wear, plastic deformation, and rolling contact fatigue (RCF). Project MU20 investigates the interaction between wear and RCF of rails and focuses on two main issues: (i) the influence of wear on RCF characteristics, and (ii) strategies for rail profile updating, including automatic control of the prediction quality.

Apart from influencing the dynamic train–track interaction, as studied in other CHARMEC projects, the wear of rails influences RCF through the removal of incipient cracks, so-called crack truncation, and a continuous change of the contact geometry (see figure). These effects may be either beneficial or detrimental and it is important to discern them through modelling and simulation. When it comes to the task of profile updating, a common procedure has been to predict the wear rate based on extrapolation from a low number of consecutive load passes, which results in a low accuracy after millions of wheel passes. The improved strategy proposed here is based on interpolation in the sense that a (still small) number of load passes are analysed; however, these load passes are chosen along the history of loading and with built-in automatic error control.

A wear model (Archard's law) has been calibrated against experimental data from voestalpine Schienen's test rig in Leoben (Austria) in collaboration with project TS11. Simulation of head check crack growth under realistic RCF loading conditions has been performed in collaboration with project MU17. In the growth simulations, the technique from project MU17 using "material forces" has been employed. With the present numerical tool, the growth of edge cracks under RCF loading conditions can be simulated for different wheel loads (contact pressure and fluid pressurization) and surface conditions (friction and wear coefficients). The computational model allows parametric studies to be carried out in order to assess conditions for RCF crack growth, e g, kinking/branching behaviour of head checks. So-called Tγ (T gamma) curves over the dissipated contact energy have been established. The influence of material

PhD student Jim Brouzoulis (left; licentiate gained in May 2010 and his supervisors Professor Magnus Ekh (right) and Docent Fredrik Larsson. For a photo of Docent Anders Ekberg, see page 67 anisotropy in the surface layer of the rail on crack propagation has been studied in a co-operative effort, see under projects MU19 and MU24.

Jim Brouzoulis presented his licentiate thesis (see below) on 7 May 2010 with Docent Bo Alfredsson of KTH Solid Mechanics introducing the discussion at the licentiate seminar. Project MU20 is being presented and discussed during biannual workshops with participants from University of Leoben (Austria), voestalpine Schienen and CHARMEC, see page 114. The research plan for project MU20 is dated 2006-11-22. It is planned that Jim Brouzoulis will defend his doctoral dissertation (see below) in October 2012.

Jim Brouzoulis, Johan Tillberg, Fredrik Larsson and Kenneth Runesson: Propagation of a single crack under RCF conditions using the concept of material forces, *Proceedings 22nd Nordic Seminar on Computational Mechanics (NSCM-22),* Aalborg (Denmark) October 2009, pp 277-279

Jim Brouzoulis: Numerical simulation of crack propagation and wear in rails, Licentiate Thesis, *Chalmers Applied Mechanics,* Gothenburg May 2010, 47 pp (Summary and two appended papers)

Jim Brouzoulis and Johan Tillberg: Propagation of a single head check crack under RCF conditions, *16th Nordic Seminar on Railway Technology,* Nynäshamn (Sweden) September 2010, 1+17 pp (Summary and PowerPoint presentation. Documented on CD)

Jim Brouzoulis: On crack propagation in rails under RCF loading conditions, *Proceedings 23rd Nordic Seminar on Computational Mechanics (NSCM-23)*, Stockholm (Sweden) October 2010, pp 42-44

Jim Brouzoulis, Peter Torstensson, Richard Stock and Magnus Ekh: Prediction of wear and plastic flow in rails – test rig results, model calibration and numerical prediction, *Wear,* vol 271, nos 1-2, 2011, pp 92-99 (also listed under project TS11)

Jim Brouzoulis, Fredrik Larsson and Kenneth Runesson: Strategies for planar crack propagation based on the concept of material forces, *Computational Mechanics,* vol 47, no 3, 2011, pp 295-304

Jim Brouzoulis and Magnus Ekh: Crack propagation in rails based on the concept of material forces, *Proceedings 2nd International Conference on Computational Modeling of Fracture and Failure of Materials and Structures (CFRAC 2011 / An ECCOMAS Thematic Conference),* Barcelona (Spain) June 2011, p 122

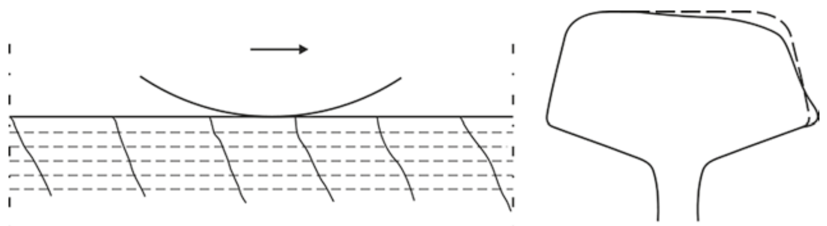
Jim Brouzoulis and Magnus Ekh: Crack propagation in rails under RCF loading conditions based on material forces, *Proceedings 24th Nordic Seminar on Computational Mechanics (NSCM-24)*, Helsinki (Finland) October 2011, pp 227-229

Jim Brouzoulis and Magnus Ekh: Crack propagation in rails under rolling contact fatigue loading conditions based on material forces, *International Journal of Fatigue* (accepted for publication)

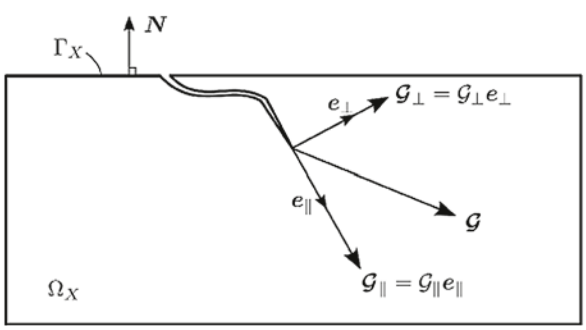
Jim Brouzoulis: Wear impact on surface crack growth in rails, *Proceedings 9th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2012),* Chengdu (China), August 2012, pp 696-705

Nasim Larijani, Jim Brouzoulis, Martin Schilke and Magnus Ekh: The effect of anisotropy on crack propagation in pearlitic rail steel, *ibidem,* pp 432-441 (also listed under projects MU19 and MU24)

Jim Brouzoulis: Numerical simulation of crack growth and wear in rails, Doctoral Dissertation, *Chalmers Applied Mechanics,* Gothenburg October 2012, 92 pp (Summary and five appended papers)



Rail deterioration with crack truncation due to wear (left) and profile change due to wear and plastic deformation (right)



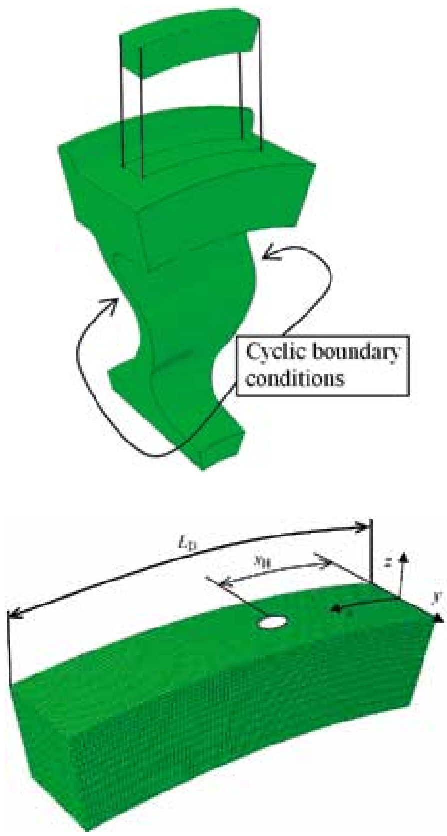
Unit base vectors which are directed parallelly and perpendicularly to the crack tip. Corresponding components of crack driving force are shown

MU21. THERMAL IMPACT ON RCF OF WHEELS

Termisk inverkan på rullkontaktutmattning av hjul
Auswirkung thermischer Prozesse auf die Rollkontaktermüdung von Rädern
Effet thermique sur la fatigue sous charge roulante des roues

Project leader and supervisor	Docent Anders Ekberg, Applied Mechanics / Division of Dynamics
Assistant supervisors	Docent Elena Kabo, Professor Magnus Ekh and Dr Tore Vernersson, Applied Mechanics
Doctoral candidate	Mr Håkan Hansson, MSc (2008-01-01 to 2008-09-19)
	Ms Sara Caprioli (from 2009-06-01; Lic Eng December 2011)
Period	2008-01-01 – 2012-06-30 (–2014-05-31)
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 700 Stage 6: kSEK 2650 Stage 7: kSEK 1860
Industrial interests in-kind budget	Stage 5: kSEK 50+200+100 Stage 6: kSEK 50+200+100 Stage 7: kSEK 50+160+50 *(Bombardier Transportation +Green Cargo+SweMaint)*

For photos of the supervisors in project MU21, see pages 65, 70 and 81



Geometry of 3D wheel model used in project MU21 with Hertzian contact load applied over an elliptic zone at moving position x_H

Rolling contact fatigue (RCF) of both rails and wheels is a widespread and serious damage phenomenon. On the wheel, RCF can lead to surface or subsurface initiated cracks that may propagate and lead to detachment of part(s) of the wheel tread followed by operational failure and, in the worst case, derailment of the train. RCF of railway wheels is the subject of several previous and ongoing CHARMEC projects, including MU4, MU9, MU10, MU18, MU22, and MU27. Thermal loading of railway wheels may also cause wheel degradation. This influence is studied in projects SD1, SD4, and SD7. The current project, MU21, focuses on railway wheels under the interaction of mechanical loading (due to rolling and/or sliding wheel–rail contact) and thermal loading (due to tread braking and/or wheel–rail friction). The heating affects the material properties (decreased yield limit, increased ductility, higher propensity for wear etc) and may induce detrimental residual stresses and/or surface cracks during cooling.

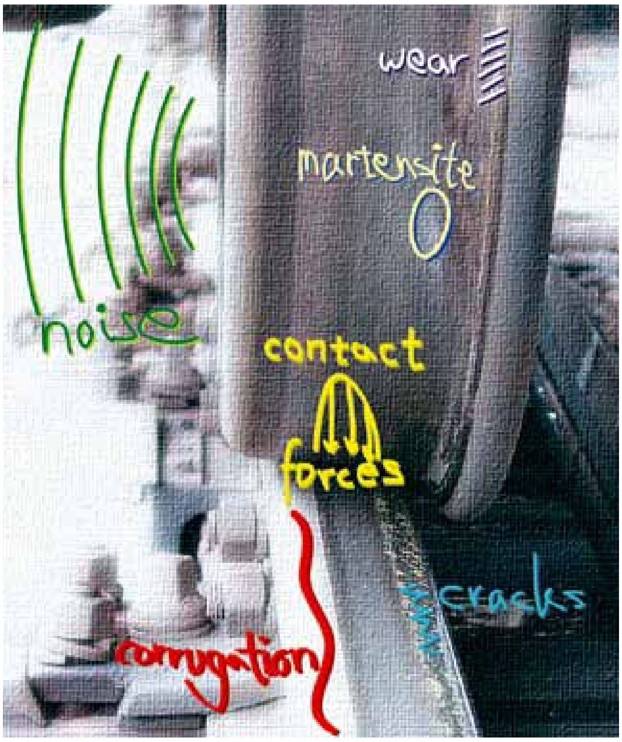
In project MU21, elastoplastic finite element (FE) simulations have been used to evaluate the impact of simultaneous thermal and mechanical loadings of the wheel tread. These loadings are combined in a three-dimensional (3D) sequentially coupled analysis where nodal temperatures from a transient thermal analysis are applied as predefined fields in the structural analysis. The mechanical contact load is prescribed as a moving Hertzian contact stress distribution on the wheel tread, see figure. Interfacial shear stress distributions corresponding to full slip or partial slip conditions have been employed.

The necessity of a 3D analysis when dealing with the combined effect of thermal and mechanical loadings has been demonstrated. It was quantified how a combination of high traction and thermal loading has a significantly detrimental influence on the material damage. For a given total tangential force, partial slip conditions result in larger plastic strain magnitudes, compared to a full slip, in a thin layer of the wheel tread near the contact surface.

Tread cracking due to severe tread braking has also been studied. This cracking has been found to be a quasi-static phenomenon where the characteristics (lengths) of the resulting cracks are governed by the peak thermal loading. A criterion for static fracture was therefore

PhD student Sara Caprioli together with Mr Steven Cervello at her licentiate seminar on 20 December 2011

used to identify both the critical size when existing surface cracks are prone to propagate and the resulting crack lengths after propagation. It was found that a fully functional brake system is not likely to induce thermal crack propagation under normal stop braking. However, with pre-existing defects on the tread, a severe drag braking due to a malfunctioning brake system may cause very deep cracking.



Phenomena related to wheel–rail contact (Anders Ekberg 2003)

Sara Caprioli presented her licentiate thesis (see below) at a seminar on 20 December 2011 with Mr Steven Cervello of Lucchini RS in Italy introducing the discussion. The research plan for project MU21 is dated 2006-11-22. For the joint reference group of projects MU18, MU21, MU22 and MU25, see project MU18.

Sara Caprioli, Tore Vernersson, Anders Ekberg and Elena Kabo: Thermal cracking of a railway wheel tread due to tread braking – critical crack sizes and influence of repeated thermal cycles, *Proceedings International Heavy Haul Association Special Technical Session (IHHA STS 2011),* Calgary (Canada) June 2011, 8 pp (documented on CD)

Sara Caprioli: Combined thermal and mechanical loading of railway wheel treads – a numerical study of material response and cracking under braking conditions, Licentiate Thesis, *Chalmers Applied Mechanics,* Gothenburg December 2011, 69 pp (Summary and three appended papers)

Sara Caprioli and Anders Ekberg: Numerical evaluation of the material response of a railway wheel under thermomechanical braking conditions, *Proceedings 9th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2012),*Chengdu (China) August 2012, pp 460-467

Sara Caprioli, Tore Vernersson and Anders Ekberg: Thermal cracking of a railway wheel tread due to tread braking – critical crack sizes and influence of repeated thermal cycles, *IMechE Journal of Rail and Rapid Transit* (accepted for publication)

MU22. IMPROVED CRITERION FOR SURFACE INITIATED RCF

Förbättrat kriterium för ytinitierad rullkontaktutmattning
Verbessertes Kriterium für oberflächeninitiierte Rollkontaktermüdung
Critère amélioré de la fatigue due au contact roulant initiée en surface

Project leader	Docent Anders Ekberg, Applied Mechanics / Division of Dynamics
Co-workers	Docent Elena Kabo and Professor Roger Lundén, Applied Mechanics
Doctoral candidate	None (only senior researchers in this project)
Period	2007-07-01–2012-06-30 (–2015-06-30)
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 700 Stage 6: kSEK 200 Stage 7: kSEK 500
Industrial interests in-kind budget	Stage 5: kSEK 100+200+100 Stage 6: kSEK 50+100+50 Stage 7: kSEK 50+100+50 *(Bombardier Transportation +Lucchini Sweden+SweMaint)*

In the previous project MU9, an engineering model to predict rolling contact fatigue (RCF) was developed. The model was named FIERCE (Fatigue Index Evaluator for Rolling Contact Environments) and it comprises modules to predict RCF initiated at the surface, below the surface and at deep material defects. Today, FIERCE is probably the only existing model with a physically based prediction of subsurface initiated RCF, which is suitable for incorporation in simulations of dynamic train–track interaction. The model is implemented in commercial packages such as ADAMS/Rail and GENSYS.

The current project refines the predictive models in FIERCE. Collaboration with colleagues at KTH in Stockholm, MTAB/LKAB in Kiruna, Lucchini RS in Italy and Transnet in South Africa has taken place. In particular, damage to locomotive wheels on the Iron Ore Line in Sweden has been investigated.

Anders Ekberg and Roger Deuce of Bombardier Transportation Germany held a presentation on 3 May 2011, reporting on their investigation of the root causes of winter problems with focus on mechanical issues. Anders Ekberg and Elena Kabo were invited as speakers to the 2nd International Squat Workshop, see below. Anders Ekberg and Elena Kabo co-operate with Roger Enblom and Babette Dirks of KTH in MU22 as well as in the parallel research project SWORD at KTH.

A number of damage analyses and improvement studies have been conducted under the umbrella of project MU22. Roger Lundén, Björn Paulsson and Anders Ekberg were invited to contribute to the "Wheel/Rail Interface Handbook" and Anders Ekberg delivered a Keynote Lecture at the CM2012 conference. A review of the research carried out at Chalmers on the subject of Transport Safety was made in 2011 under the chairmanship of Anders Ekberg, and included open seminars in Hallsberg on 2010-05-27 and at Chalmers on 2011-10-21.

The research plan for project MU22 is dated 2006-11-22. Projects MU18, MU21, MU22 and MU25 have a joint reference group, see project MU18.

From the left: Docent Anders Ekberg, Docent Elena Kabo and Professor Roger Lundén during a close inspection

Co-workers in projects MU26 and MU27 outside the building of Mathematical Sciences on Chalmers campus

Roger Lundén and Björn Paulsson: Introduction to wheel-rail interface research, *Wheel-rail interface handbook* (editors Roger Lewis and Ulf Olofsson), *Woodhead Publishing,* Cambridge (UK) 2009, pp 3-33

Anders Ekberg: Fatigue of railway wheels, *ibidem*, pp 215-244

Elena Kabo, Anders Ekberg, Peter Torstensson and Tore Vernersson: Rolling contact fatigue prediction for rails and comparison with test rig results, *IMechE Journal of Rail and Rapid Transit*, vol 224, no F4, 2010, pp 303-317 (also listed under project EU10)

Anders Ekberg and Elena Kabo: Utmattning av järnvägshjul (Fatigue of railway wheels; in Swedish), *16th Nordic Seminar on Railway Technology,* Nynäshamn (Sweden) September 2010, 1+16 pp (Summary and PowerPoint presentation. Documented on CD)

Elena Kabo, Anders Ekberg, Peter Torstensson and ToreVernersson: Prediction of rolling contact fatigue from bench tests of rail materials, *ibidem,* 1+15 pp

Elena Kabo, Roger Enblom and Anders Ekberg: A simplified index for evaluating subsurface initiated rolling contact fatigue from field measurements, *Wear,* vol 271, nos 1-2, 2011, pp 120-124

Per Gullers, Paul Dreik, Jens Nielsen, Anders Ekberg and Lars Andersson: Track condition analyser – identification of rail rolling surface defects, likely to generate fatigue damage in wheels, using instrumented wheelset measurements, *IMechE Journal of Rail and Rapid Transit,* vol 225, no F1, 2011, pp 1-13 (also listed under project SP11). Authors received the 2011 SAGE Best Paper Award

Elena Kabo and Anders Ekberg: Förstudie – möjlighet att identifiera inspektionsintervall för ringade lokhjul (Prestudy – possibility to identify inspection intervals for tyred locomotive wheels; in Swedish), Gothenburg 2011, 9 pp (availability restricted)

Anders Ekberg, Mikael Hägg, Monica Lundh, Deborah Mitchell, Jonas Ringsberg and Mats Svensson: Transport safety – research at Chalmers today and in the future, *Chalmers Applied Mechanics,* Gothenburg 2011, 66 pp

Anders Ekberg, Bengt Åkesson and Elena Kabo: Rolling contact fatigue of wheels and rails – probe, predict, prevent (Keynote Lecture), *Proceedings 9th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2012),* Chengdu (China) August 2012, pp 29-41

Anders Ekberg, Elena Kabo, Tore Vernersson and Roger Lundén: Förstudie – minimering av hjulskador (Prestudy – minimization of wheel damage; in Swedish), *Chalmers Applied Mechanics,* Gothenburg 2012, 35 pp and 2 appendices (availability restricted)

MU23. MATERIAL BEHAVIOUR AT RAPID THERMAL PROCESSES

Materialbeteende vid snabba termiska förlopp
Materialverhalten bei schnellen thermischen Prozessen
Comportement des matériaux sous processus thermiques rapides

Project leaders and supervisors	Docent Johan Ahlström, Senior Lecturer, and Professor Christer Persson (succeeding Professor Birger Karlsson), Materials and Manufacturing Technology
Doctoral candidate	Mr Krste Cvetkovski (from 2007-10-15; Lic Eng April 2010)
Period	2007-10-01 – 2012-06-30 (–2012-10-31)
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 2600 Stage 6: kSEK 4500 Stage 7: kSEK 500
Industrial interests in-kind budget	Stage 5: kSEK 100+200 Stage 6: kSEK 100+300 Stage 7: kSEK 50+100 *(Banverket/Trafikverket + voestalpine Bahnsysteme)*

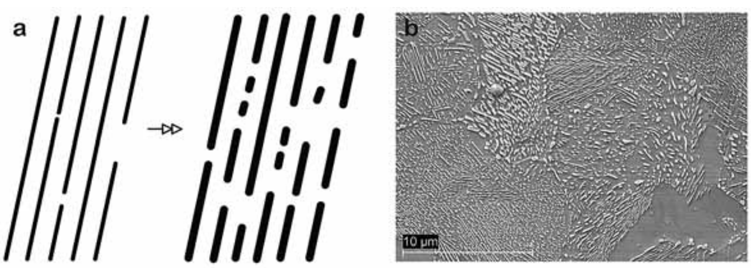
This is a combined senior and doctoral project

Phenomena behind thermal damage on wheels and rails can be malfunctioning brakes and/or anti-skid devices and irregular wheel and rail surfaces, and two-point contact between wheel and rail as is often occurring on curved track. Here, spatially concentrated and very high friction forces mean that a small material volume can be heated to austenite (at about 750°C) within a few milliseconds. During the following rapid cooling caused by the surrounding cold steel, the material in this volume can be transformed into martensite, and cracks may arise and a complex residual stress field be induced. Repeated heating of material volumes to lower (moderate) temperatures can result in progressive softening, leading to impaired material performance. Project MU23 combines experimental studies and numerical modelling to examine material aspects of combined thermal and mechanical loading.

Two wheel steel grades with different levels of silicon and manganese were investigated: the R8T grade (corresponding to European ER8) and a more high-alloyed grade with 1.0 wt % silicon and 0.95 wt % manganese, here denoted HiSi. Both grades are commonly used in Europe for wheels on passenger trains with disc brakes. Treads and flanges are rim chilled during production, resulting in a fine pearlitic microstructure. In their virgin state, the two steels were found to have fairly similar mechanical characteristics over a wide range of temperatures and strain rates. Upon annealing, both materials begin to soften at temperatures above 500°C. Investigation of the microstructure revealed that the softening of R8T was caused by spheroidization of cementite lamellae in pearlite. Higher temperatures and heavy predeformation before annealing emphasized this degeneration. As the HiSi steel has a higher resistance against microstructural degeneration at elevated temperatures, it retains its mechanical properties better after high temperature exposure. This is particularly evident for the fatigue performance. The fatigue life after annealing differs between the two materials by as much as a factor three in favour of the HiSi steel.

Wheels taken out of service have also been investigated. Here, microscopy techniques (OM, SEM) were used to study crack cluster networks and surface RCF. Microhardness measurements were carried out and spectroscopy techniques (EDX, AES) were used to analyse composition and oxygen concentration. Mixed mode crack propagation with internal fretting between crack faces was believed to cause crack branching. The cracks contained layered structures of work-hardened base material which had been sheared to flakes. Head checks and deeper cracks showed similar structures, a fact which is surprising considering their different environments, especially regarding exposure to water and other fluids.

To simulate thermal damage of wheel material in service, samples of both virgin material and material taken from the deformed surface layer of used wheels were exposed to heating pulses. Material strength was characterized before and after thermal exposure. Thermal treatment of virgin material was done with short-time laser heat pulses in cooperation with Materials Center Leoben in Austria, while the deformed material was heated in our laboratory using resistive heating. After short thermal exposures at moderate temperatures, the strength was found to be relatively well preserved, which explains why the repetitive mechanical and short thermal impacts encountered during normal service can be endured.

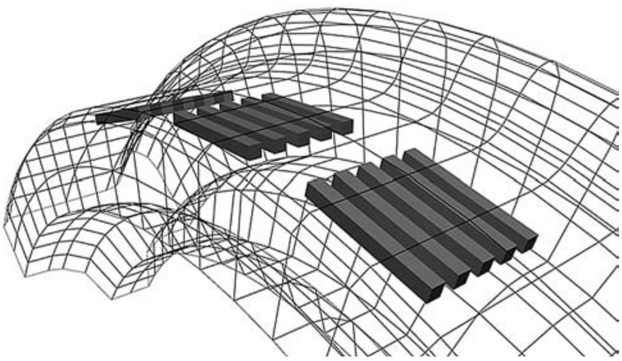


Spheroidization of pearlite, as studied in project MU23, with morphology change appearing as a reduction in lamellar length and an increase in lamellar thickness: (a) Schematic sketch and (b) scanning electron micrograph of spheroidized microstructure

PhD student Krste Cvetkovski (middle; licentiate gained in April 2010) and his supervisors Docent Johan Ahlström (right) and Professor Christer Persson in project MU23

Based on experimental findings within this project, a model for calculation of residual stresses from local thermal pulses was formulated within the senior part of project MU23. The paper for ICTPMCS4 (see below) and a more detailed article on thermal damage and residual stresses were both written with the combined efforts of the doctoral student and the senior researcher.

The reference group for project MU23 includes members from Bombardier Transportation (Sweden and Germany/Siegen), Interfleet Technology, Lucchini Sweden and Trafikverket. The research plan for project MU23 is dated 2007-01-22. Krste Cvetkovski presented his licentiate thesis (see below) at a seminar on 23 April 2010 where Dr Thomas Hansson of Volvo Aero Corporation (Sweden) introduced the discussion. It is planned that Krste Cvetkovski will defend his doctoral dissertation (see below) in October 2012.



Position of samples extracted from wheel at an approximate depth of 15 mm below tread in project MU23

Krste Cvetkovski: Temperature stability of railway wheel steels – influence on microstructure and mechanical properties, Licentiate Thesis, *Chalmers Materials and Manufacturing Technology,* Gothenburg April 2010, 62 pp (Summary and two appended papers)

Johan Ahlström, Krste Cvetkovski, Birger Karlsson and Ingo Siller: Short-time tempering kinetics of quench hardened pearlitic steels, *Proceedings 4th International Conference on Thermal Process Modeling and Computer Simulation (ICTPMCS4),* Shanghai (China) May-June 2010, 6 pp (documented on USB)

Krste Cvetkovski, Johan Ahlström and Birger Karlsson: Thermal softening of fine pearlitic steel and its effect on the fatigue behaviour, *Procedia Engineering,* vol 2, no 1, 2010, pp 541-545 (presented at *10th International Fatigue Congress (IFC10)* in Prague (Czech Republic) June 2010)

Krste Cvetkovski: Wheel materials with improved resistance against thermal damage, *16th Nordic Seminar on Railway Technology,* Nynäshamn (Sweden) September 2010, 1+21 pp (Summary and PowerPoint presentation. Documented on CD)

Krste Cvetkovski and Johan Ahlström: Characterisation of plastic deformation and thermal softening of the surface layer of railway passenger wheel treads (submitted for international publication)

Krste Cvetkovski, Johan Ahlström and Birger Karlsson: Influence of short heat pulses on properties of martensite in medium carbon steels (submitted for international publication)

Krste Cvetkovski, Johan Ahlström and Christer Persson: Subsurface crack networks and RCF surface cracks in pearlitic railway wheels, *Proceedings 9th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2012)*, Chengdu (China) August 2012, pp 425-431

Krste Cvetkovski: Influence of thermal loading on mechanical properties of railway wheel steels, Doctoral Dissertation, *Chalmers Materials and Manufacturing Technology,* Gothenburg October 2012, 101 pp (Summary and six appended papers)

MU24. HIGH-STRENGTH STEELS FOR RAILWAY RAILS

Höghållfasta stål för järnvägsräls
Hochfeste Stähle für Eisenbahnschienen
Aciers à haute résistance pour les rails de chemin de fer

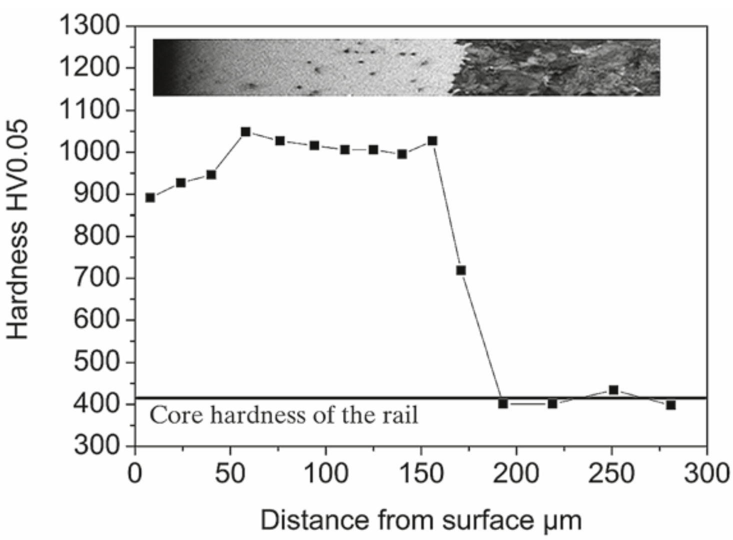
Project leaders and supervisors	Professor Christer Persson, (succeeding Professor Birger Karlsson), Materials and Manufacturing Technology
Assistant supervisor	Professor Magnus Ekh, Applied Mekanics
Doctoral candidate	Mr Martin Schilke (from 2007-10-15; Lic Eng June 2011)
Period	2007-10-01 – 2012-06-30 (– 2012-10-31)
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 1500 Stage 6: kSEK 2700 Stage 7: kSEK 400
Industrial interests in-kind budget	Stage 5: kSEK 100+300 Stage 6: kSEK 100+300 Stage 7: kSEK 100+300 *(Banverket/Trafikverket + voestalpine Bahnsysteme)*

The competitiveness of railway transportation calls for longer rail life. This is a challenging demand today because the deterioration of rail materials in service can be expected to accelerate due to higher speeds and axle loads in new railway systems. The primary aim of project MU24 is to investigate crack nucleation and crack growth in high-strength rail steels under fatigue conditions.

Historically, rail grades have been made increasingly harder in order to counteract wear and thereby prolong the life of rails in service. However, increasing hardness usually increases the susceptibility to crack initiation and crack growth. Two high-strength rail steels were investigated in this project, R350HT and R400HT, both of which are fully pearlitic and heat treated to achieve higher hardness. The means of investigation were low-cycle fatigue testing and tensile testing. The higher hardness grade, R400HT, exhibited longer fatigue life and higher tensile strength than the R350HT grade (in our uniaxial strain-controlled push-pull tests). Samples from rails in service at different sites in Sweden have been studied with optical microscopy. It was found that they exhibit a deformed top layer displaying plastic flow and an irregular pattern of cracks.

A problem which occurs in track and not in laboratory tests is the formation of so-called white etching layers (WEL). Under the pressure of the wheels combined with the elevated temperature caused by friction, the top layer of a rail can undergo a dramatic microstructural change, which results in the hardness being two to three times higher than that of the original structure (see diagram). The WEL layer is more brittle than the base material and martensite seems to be its main constituent. WEL on rails are much thicker (up to 200 μm) than those found in other circumstances, e g, in gears. A satisfying explanation of how WEL are created is lacking. Cracks can form in the WEL or at the interface between WEL and the base material. Other effects, like corrugation, might be connected to WEL.

Martin Schilke presented his licentiate thesis (see below) at a seminar on 8 June 2011 with Professor Johan Moverare of Linköping University (Sweden) and Siemens Industrial Turbomachinery acting as discussion leader. The research plan for project MU24 is dated 2007-01-22. The reference group for the project has members from Trafikverket and voestalpine Schienen.



Measured hardness profile through white etching layer on rail head

PhD student Martin Schilke (middle; licentiate gained in June 2011) and his supervisors Professor Christer Persson (right) and Professor Magnus Ekh in project MU24

Martin Schilke and Johan Ahlström: Laboratory test data of material properties, Appendix C in INNOTRACK Deliverable 3.1.6, Recommendations of, and scientific basis for, optimisation of switches & crossings – part 2 (see project EU10)

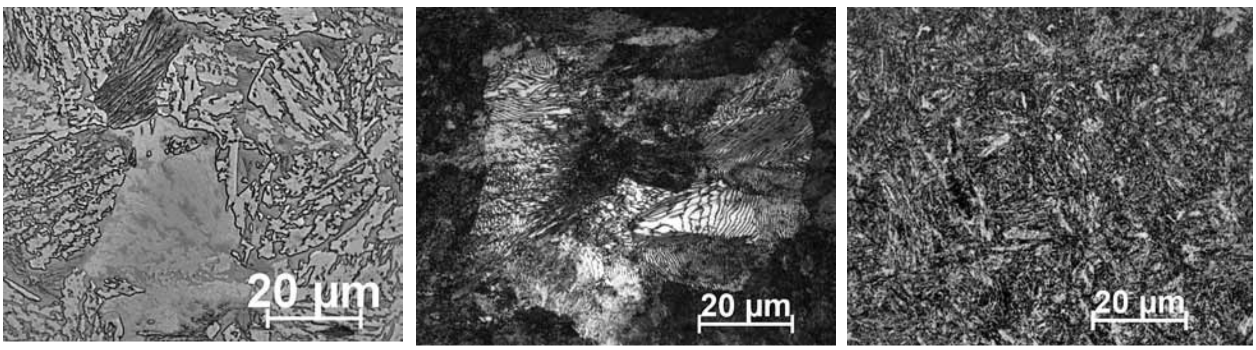
Martin Schilke, Johan Ahlström and Birger Karlsson: Low cycle fatigue and deformation behaviour of austenitic manganese steel in rolled and in as-cast conditions, *Procedia Engineering*, vol 2, no 1, 2010, pp 623-628 (presented at *10th International Fatigue Congress (IFC10)* in Prague (Czech Republic) June 2010)

Martin Schilke: Rail materials for switches and crossings, *16th Nordic Seminar on Railway Technology,* Nynäshamn (Sweden) September 2010, 1+17 pp (Summary and PowerPoint presentation. Documented on CD)

Martin Schilke: Comparability of railway rail steels low cycle fatigue behaviour, Licentiate Thesis, *Chalmers Materials and Manufacturing Technology*, Gothenburg June 2011, 68 pp (Introduction and two appended papers)

Martin Schilke and Christer Persson: White etching layers on the Stockholm local traffic network, *Proceedings 9th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2012),* Chengdu (China), August 2012, pp 589-596

Nasim Larijani, Jim Brouzoulis, Martin Schilke and Magnus Ekh: The effect of anisotropy on crack propagation in pearlitic rail steels, *ibidem,* pp 432-441 (also listed under projects MU19 and MU20)



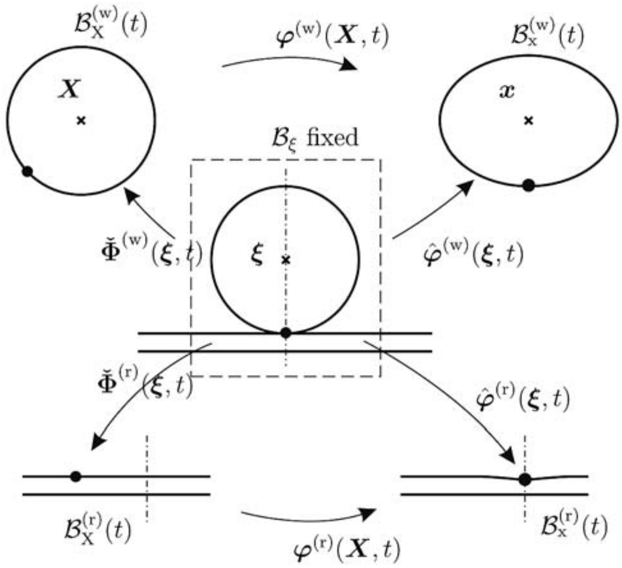
Micrographs of three rail steels studied in project MU24. From the left: bainitic, pearlitic and martensitic microstructure

MU25. THERMODYNAMICALLY COUPLED CONTACT BETWEEN WHEEL AND RAIL

Termomekaniskt kopplad kontakt mellan hjul och räl
Thermomechanisch gekoppelter Kontakt zwischen Rad und Schiene
Couplage thermodynamique du contact entre roue et rail

Project leader and supervisor	Docent Anders Ekberg Applied Mechanics/ Division of Dynamics
Assistant supervisors	Docent Fredrik Larsson and Professor Kenneth Runesson, Applied Mechanics
Doctoral candidate	Mr Andreas Draganis (from 2009-06-29; Lic Eng December 2011)
Period	2009-01-01 – 2012-06-30 (–2014-06-30)
Chalmers budget (excluding university basic resources)	Stage 5: – Stage 6: kSEK 2400 Stage 7: kSEK 2000
Industrial interests in-kind budget	Stage 5: – Stage 6: – Stage 7: –

The project has been partially financed by The Swedish Research Council, VR (through CHARMEC's budget)



Spatial (current) configuration $B_x(t)$, material configuration $B_X(t)$ and absolute (fixed) configuration B_ξ for each of two bodies w(heel) and r(ail). From the application to VR

Project MU25 investigates and develops efficient methods for modelling and computation of the thermomechanically coupled problem when two deformable bodies are in high-speed sliding contact. A typical example is a braked (and locked) railway wheel that moves along the rail. A major challenge here is to formulate a computationally efficient description of the motion of the two bodies. In particular, such a description should account for the high accuracy needed in the moving contact patch. A significant motivation for the current study is the possibility to allow for refined predictions of different forms of rolling contact damage to wheels and rails.

To achieve these aims, the ALE (Arbitrary Lagrangian-Eulerian) kinematical description is employed. This is a generalization of the traditional Lagrangian and Eulerian descriptions. The Lagrangian description follows when the initial configuration of the bodies is taken as the reference configuration. This means that a computational finite element (FE) mesh will be fixed to material points during deformation. This description naturally allows easy tracking of boundaries and easy treatment of history-dependent material parameters, but can lead to severe degradation of the element mesh at large displacements. In the Eulerian description, the current configuration is instead chosen as the reference. This implies that a computational mesh will be fixed in space. In this description, keeping track of boundaries and history-dependent material parameters may be very difficult, while large displacements/distortions of the continuum are easily handled.

With the given choice of intermediate configurations (see figure) pertinent to the ALE model as basis, the equations of motion of the mechanical system have been established and finite element (FE) formulations derived. The theoretical and numerical framework for rolling contact simulation setting out from the ALE kinematical model has been finalized and validated for mechanical two-dimensional (2D) contact. Implemented features include 2D cylinder–plate contact, transient dynamics, non-reflecting boundary conditions and customizable surface profiles, allowing for the implementation of non-smooth surface profiles. Additional features include a penalty-type formulation of thermal contact and a numerical stabilization scheme. Studies of frictional contact, wheel–rail heat partitioning and temperature distributions for different operational cases are currently being carried out.

Andreas Draganis presented his licentiate thesis (see below) at a seminar on 21 December 2011 with Professor Mathias Wallin of the Division of Solid Mechanics in the Faculty of Engineering at Lund University (Sweden) introducing the discussion at the seminar. The research plan (from the approved first application to VR for three years) is dated 2008-04-15. An application for continued financing from VR was rejected. For the joint reference group, see under project MU18.

PhD student Andreas Draganis (second from the right; licentiate gained in December 2011) and his supervisors Docent Anders Ekberg (left), Docent Fredrik Larsson (second from the left) and Professor Kenneth Runesson in project MU25. Photo taken in 2009

Andreas Draganis, Fredrik Larsson and Anders Ekberg: An Arbitrary Lagrangian-Eulerian formulation for simulation of wheel–rail contact, *Proceedings 23rd Nordic Seminar on Computational Mechanics (NSCM-23),* Stockholm (Sweden) October 2010, pp 173-176

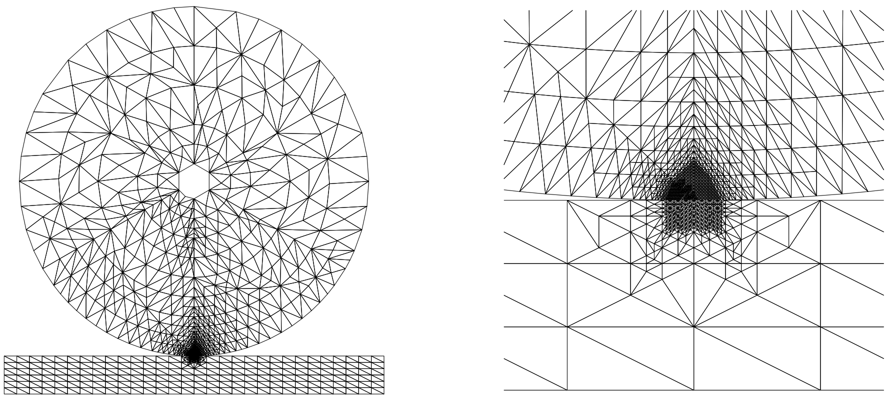
Andreas Draganis, Fredrik Larsson and Anders Ekberg: Rolling contact stress evaluations under non-smooth conditions using an arbitrary Lagrangian-Eulerian formulation, *Proceedings International Tribology Conference 2011 (ITC 2011)*, Hiroshima (Japan) October-November 2011, extended abstract 1 p

Andreas Draganis: Numerical simulation of thermomechanical rolling contact using an arbitrary Lagrangian-Eulerian formulation, Licentiate Thesis, *Chalmers Applied Mechanics,* Gothenburg December 2011, 46 pp (Summary and two appended papers)

Andreas Draganis, Fredrik Larsson and Anders Ekberg: Numerical evaluation of the transient response due to non-smooth rolling contact using an arbitrary Lagrangian-Eulerian formulation, *IMechE Journal of Engineering Tribology,* vol 226, no J1, 2012, pp 36-45

Andreas Draganis, Fredrik Larsson and Anders Ekberg: Modelling the thermomechanical wheel–rail interface during rolling contact, *Proceedings 9th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2012),* Chengdu (China) August 2012, pp 451-459

Andreas Draganis, Fredrik Larsson and Anders Ekberg: Finite element analysis of transient thermomechanical rolling contact using an efficient arbitrary Lagrangian-Eulerian description (submitted for international publication)



Two-dimensional finite element mesh, with a zoomed-in view of the refined wheel–rail contact region, used in project MU25

MU26. OPTIMUM INSPECTION AND MAINTENANCE OF RAILS AND WHEELS

Optimal inspektion och optimalt underhåll av räler och hjul
Optimal Besichtigung und optimaler Unterhalt von Schienen und Rädern
Inspection optimal et entretien optimale des rails et roues

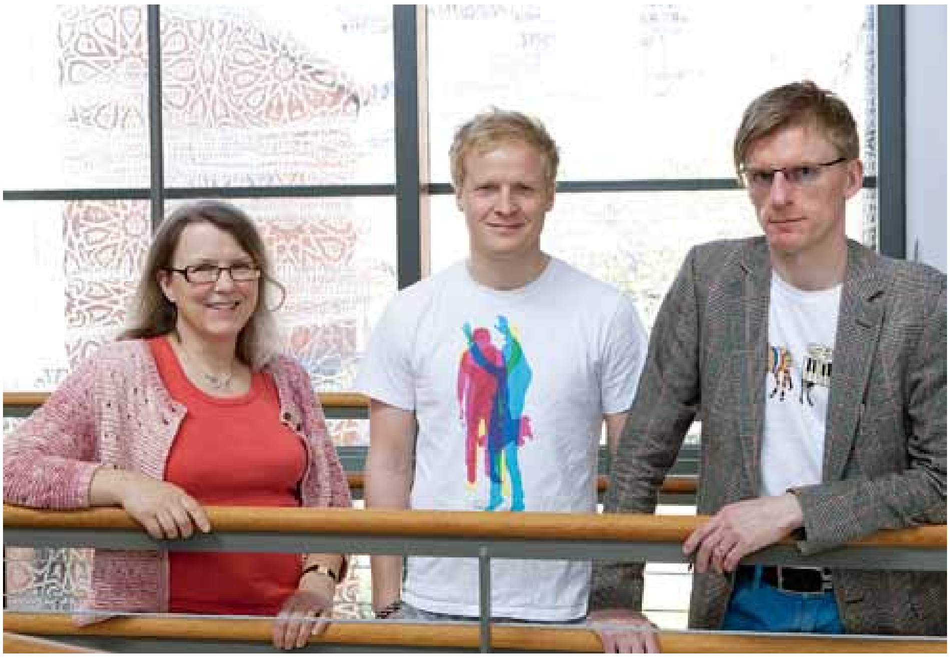
Project leader and supervisor	Docent Ann-Brith Strömberg, Mathematical Sciences / Division of Mathematics / Optimization
Assistant supervisors	Docent Anders Ekberg, Applied Mechanics, and Professor Michael Patriksson, Mathematical Sciences
Doctoral candidate	Mr Emil Gustavsson, MSc (from 2010-08-15)
Period	2010-08-15 – 2015-08-14
Chalmers budget (excluding university basic resources)	See below
Industrial interests in-kind budget	Stage 6: – Stage 7:–

The project is financed by the joint Department of Mathematical Sciences at Chalmers University of Technology and Gothenburg University

Continuously increasing train speeds and axle loads lead to a higher rate of deterioration and a shorter operational life of rails and wheels, and also to an increased failure risk. These negative effects may be significantly limited through suitable design and maintenance. To improve the efficiency of maintenance and prevent extreme operational disturbances, an optimal planning of the maintenance is desirable. Project MU26 develops decision support tools for optimization (observing time periods, physical locations, and types of activities) of inspection and maintenance of rails and wheels with respect to life cycle costs, while retaining safe and profitable operations. The tools are based on mathematical models and take into account the costs of inspections and maintenance, the costs of traffic disturbances and delays, the logistics of maintenance operations, required maintenance, inspection capacity, and safety issues. The models account for the fact that degradation of rails and wheels is a progressive process. This process is being studied in the parallel project MU27.

To facilitate operational planning, the effects on inspection and maintenance activities of changes in important input data, such as maintenance capacity, traffic load, and budget, are being accounted for. Due to uncertainties in the input data, such as operational conditions and results from damage prediction models, the mathematical optimization models developed in project MU26 allow for stochastic input parameters.

Several models for maintenance planning of multi-component systems have been developed. Numerical tests are performed on system cases from railways, wind turbines and aircraft engines. The railway case concerns



PhD student Emil Gustavsson (middle) and his supervisors Docent Ann-Brith Strömberg and Professor Michael Patriksson. For a photo of Docent Anders Ekberg, see page 70

maintenance in the form of removal of rolling contact fatigue defects by rail grinding (preventive maintenance) and rail replacement (corrective maintenance). The models are developed in a MILP (Mixed Integer Linear Program) framework. Complexity analyses have been performed for these models. Access to Trafikverket's databases has been arranged. A co-ordinating decision strategy regarding the management of rail grinding in the Swedish railway system is being studied.

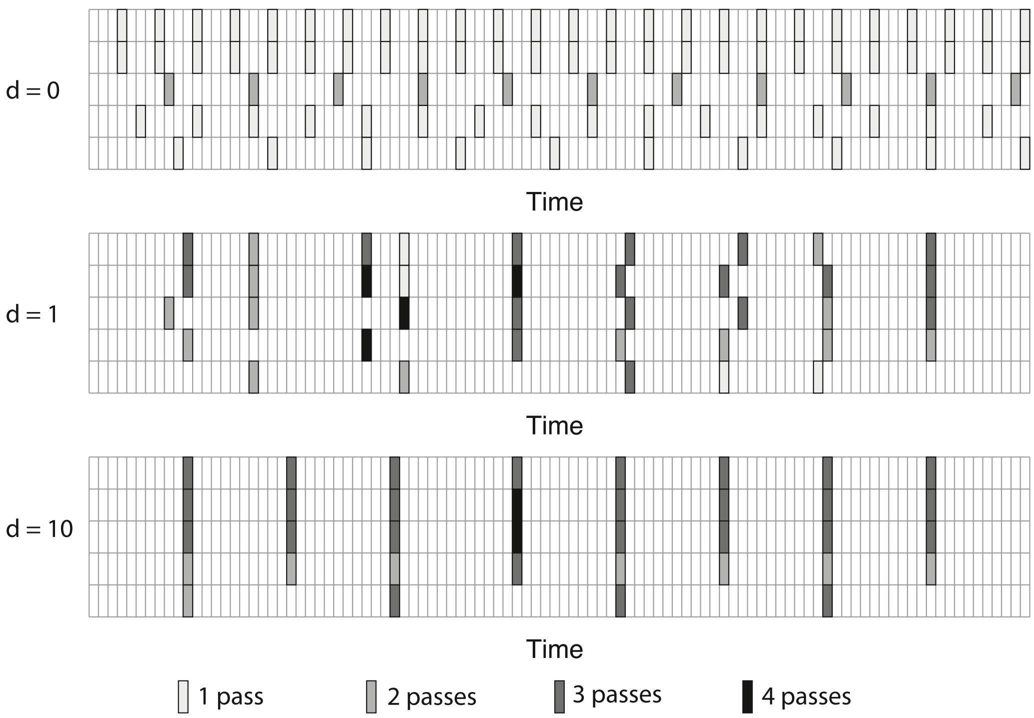
The joint reference group for projects MU26 and MU27 has members from Chalmers Applied Mechanics, Chalmers Mathematical Sciences, Interfleet Technology, SP Technical Research Institute of Sweden, and Trafikverket. The research plan for project MU26 is dated 2010-05-27.

Emil Gustavsson: Underhållsoptimering – tillämpningar i järnvägsindustrin (Maintenance optimization – applications in the railway industry; in Swedish), *Svenska Operationsanalysföreningen (Swedish Operation Research Association; SOAF/SORA) Conference SOAF 2011,* Kista (Sweden) September 2011

Emil Gustavsson, Michael Patriksson and Ann-Brith Strömberg: Primal convergence from dual subgradient methods for convex optimization, *21st International Symposium on Mathematical Programming (ISMP 2012)*, Berlin (Germany) September 2012

Emil Gustavsson: An optimization model for preventive rail grinding, *ibidem*

Emil Gustavsson, Michael Patriksson, Ann-Brith Strömberg, Adam Wojciechowski and Magnus Önnheim: The preventive maintenance scheduling problem (to be submitted for international publication)



Optimal rail grinding schedules – assuming that the degradation speed increases with time – for three distinct values of the maintenance occasion cost *d*. The term "pass" refers to "pass with the grinding machine at the maintenance occasion"

MU27. PROGRESSIVE DEGRADATION OF RAILS AND WHEELS

Progressiv nedbrytning av räler och hjul
Progressive Degradierung von Schienen und Rädern
Dégradation progressive des rails et roues

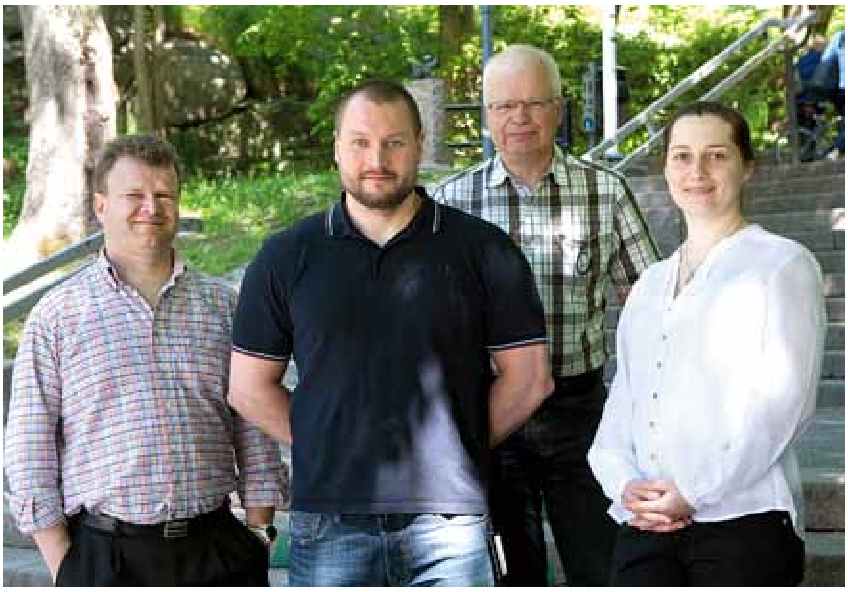
Project leader and supervisor	Docent Elena Kabo, Applied Mechanic / Division of Material and Computational Mechanics
Assistant supervisors	Docent Anders Ekberg, Applied Mechanics, and Professor Michael Patriksson, Mathematical Sciences
Doctoral candidate	Mr Kalle Karttunen, MSc (from 2010-10-15)
Period	2010-10-15 – 2012-06-30 (–2015-10-31)
Chalmers budget (excluding university basic resources)	Stage 6: kSEK 1500 Stage 7: kSEK 3100
Industrial interests in-kind budget	Stage 6: kSEK – Stage 7: kSEK 200+50 *(Trafikverket +Interfleet Technology)*

When carrying out an optimization of inspection, maintenance and operational parameters to obtain a balance that reduces the life cycle costs of railway infrastructure and railway operations, it is vital to understand and be able to formulate and quantify the deterioration of key components. Project MU27 focuses on the evolving deterioration of rails and wheels during operational loading. This process can be seen as a feedback loop where the progressive deterioration of track and vehicles influences the loading on rails and wheels, which in turn will influence the deterioration rate of wheels and rails.

This project set out by identifying current degradation models and how these relate the deterioration of rails and wheels to (altered) operational conditions. The work is carried out in close co-operation with project MU26. The intended delivery from MU27 to MU26 is extracted load and damage spectra from evaluated operational loads. These spectra should be established for all those deterioration modes and operational conditions which are to be considered.

A study on how lateral track irregularities (transverse displacements of the rails) influence track shift forces (transverse forces on the track), rolling contact fatigue (RCF) and component fatigue has been performed. Here, multibody simulations have been used incorporating a track with measured (and subsequently scaled) geometrical irregularities employing a model of an iron ore wagon.

Statistically, the track shift forces (up to moderately high levels) were found to follow a normal distribution with the standard deviation being related to the standard deviation of the lateral track irregularity spectrum. The increase in RCF has been quantified using two RCF damage criteria. They gave similar results, indicating that increased track irregularity magnitudes lead to an increase in both damage magnitudes and the number and lengths of affected track sections in shallow curves. However, lateral track irregularity magnitudes were found to have only a



PhD student Kalle Karttunen (second from the left) and his supervisors Docent Elena Kabo (right) and Docent Anders Ekberg (left) together with Professor Roger Lundén. For a photo of Professor Michael Patriksson, see page 68

moderate influence on the predicted component fatigue damage. Furthermore, a roughly linear relationship between the standard deviation of the magnitude of lateral track geometry irregularities and that of track shift forces was observed from the simulations. The wheel–rail friction coefficient (varied between 0.3 and 0.6) was found not to have a significant influence on predicted track shift forces for moderate lateral irregularities.

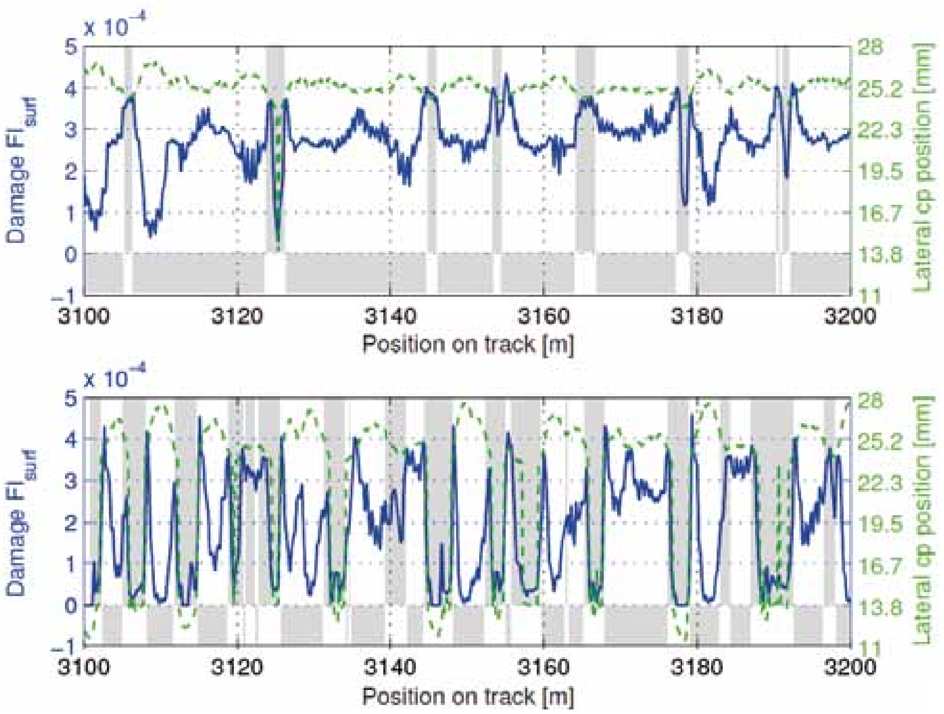
The influence of lateral irregularities on RCF was found to have a complex relation to curve radius: In sharp curves, the total length of RCF-affected track (as quantified by the surface fatigue index used) decreases with increasing lateral irregularities. This response is connected to a shift in the wheel–rail contact position and may be accompanied by a shift from uniform wear along the curve to a mix of wear and RCF-affected sections. On more shallow curves, the portion of the high rail affected by RCF increases with increasing lateral irregularities. An increased coefficient of friction in the wheel–rail interface was generally found to increase RCF damage magnitudes. In a futher numerical example, a single transverse irregularity with amplitude 6 mm and wavelengths less than 20 m were found to cause RCF on both rails and wheels because of the induced oscillation of the wheelset.

For the joint reference group, see under project MU26. The research plan for project MU26 is dated 2010-05-27.

Kalle Karttunen, Elena Kabo and Anders Ekberg: The influence of lateral track irregularities on track shift forces, rolling contact fatigue and component fatigue, *Poster at 22nd International Symposium on Dynamics of Vehicles on Roads and Tracks (IAVSD 2011)*, Manchester (UK) August 2011 (documented on CD)

Kalle Karttunen, Elena Kabo and Anders Ekberg: A numerical study of the influence of lateral geometry irregularities on mechanical deterioration of freight tracks, *IMechE Journal of Rail and Rapid Transit* (accepted for publication)

Kalle Karttunen, Elena Kabo and Anders Ekberg: The influence of track geometry irregularities on rolling contact fatigue, *Proceedings 9th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2012)*, Chengdu (China) August 2012, pp 540-546



Predicted response of the leading axle of a freight wagon negotiating a curve of radius 438 m. RCF damage as quantified by FI_{surf} (solid blue line, left vertical axis). Lateral contact position (cp) on rail (dashed green line, right vertical axis). Grey area indicates RCF (if positive according to the left vertical axis) or wear (negative) according to the Tγ criterion. Standard deviations of lateral irregularities are 0 mm (upper diagram) and 2.94 mm (lower diagram)

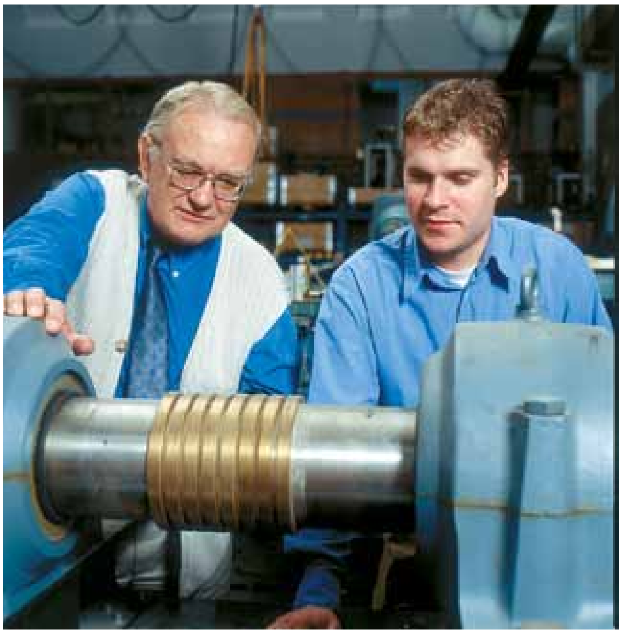
SD1. BRAKING OF FREIGHT TRAINS – A SYSTEMS APPROACH

Bromsning av godståg – en systemstudie
Bremsen von Güterzügen – eine Systemstudie
Freinage de trains fret – étude de systèmes

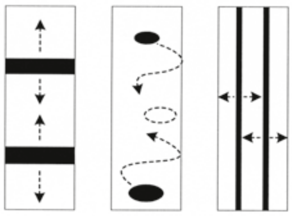
The SD1 project was completed with Daniel Thuresson's successful defence in public of his doctoral dissertation in October 2006. The faculty-appointed external examiner of the dissertation was Professor Andrew Day from the School of Engineering, Design & Technology at the University of Bradford in West Yorkshire, UK. The title of the dissertation is "Thermomechanics of block brakes". The research in project SD1 was supervised by Professor Göran Gerbert of Chalmers Machine and Vehicle Design.

Project SD1 was aimed at describing the interaction between block and wheel by use of simple (but physically correct) models. The phenomenon known as ThermoElastic Instability (TEI) was found to be the main driving force in terms of excessive pressure and temperature. TEI on a friction material appears as moving contact points caused by the interaction between wear and thermal expansion, see figure.

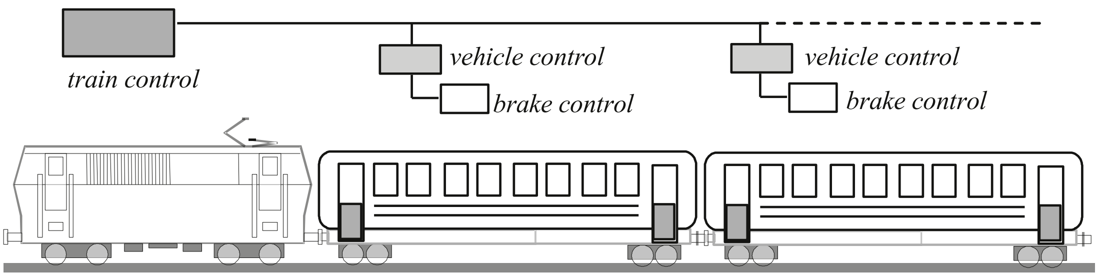
Temperature measurements on the full-scale Lucchini / CHARMEC block brake test rig at Surahammar (see pages 73, 75 and 83) were performed. Both measurements and simulations showed an unstable temperature distribution. Cast-iron brake blocks were found to be more prone to TEI than blocks made of sinter and composition materials. See also CHARMEC's Triennial Reports for Stages 2, 3 and 4. The reference group for project SD1 consisted of representatives of Faiveley Transport and Green Cargo.



PhD student Daniel Thuresson (right; doctorate earned in October 2006) and his supervisor Professor Göran Gerbert in project SD1. Photo taken in 2000 at a brake rig in the laboratory of Chalmers Machine and Vehicle Design



Sketches of the shape and size of moving contact areas on a sliding brake block when ThermoElastic Instability (TEI) occurs. Contact pressure and temperature are high over the black areas

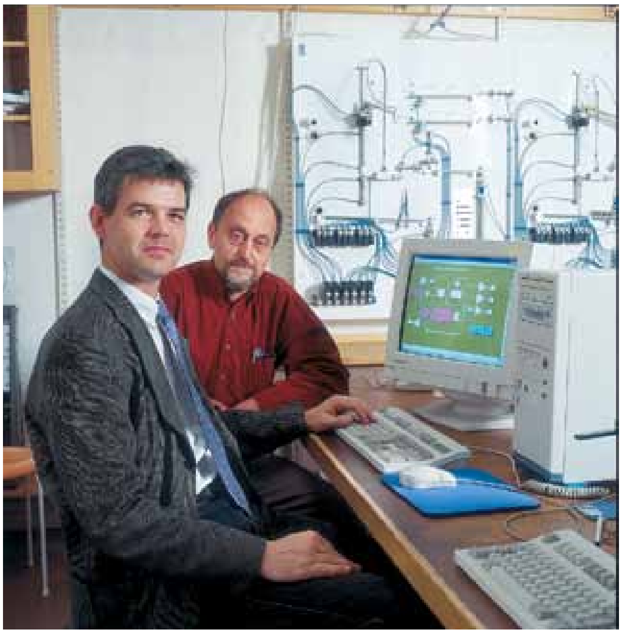


Brake control architecture studied in project SD3

SD2. SONAR PULSES FOR BRAKING CONTROL

Ljudpulser för styrning av bromsar
Schallpulse für die Steuerung von Bremsen
Contrôle de freins par pulsions sonores

The SD2 project was completed in June 2000 with a series of reports by Hans Sandholt and Bengt Schmidtbauer, see CHARMEC's Triennial Report for Stage 2. Acoustic communication (sonar transmission) through the main pneumatic brake line of a trainset (modulation of the pressure signal) was studied theoretically, numerically and experimentally. Scale-model experiments were performed at Chalmers and full-scale experiments with brake lines (including hoses, accumulators etc) up to 1200 m in length at the SAB WABCO (now Faiveley Transport) brake system simulator in Piossasco, Italy, as well as on stationary and rolling freight trains in Sweden. Sensors, actuators and software were developed. The experiments verified the theoretical/numerical models. The conclusion reached in project SD2 was that transmitting usable information in the pressurized brake line is possible, but only at a low bandwidth (5 to 10 Hz). The described sonar transmission of braking signals still awaits commercial implementation.



Lecturer Hans Sandholt, MSc, (left) and Professor Bengt Schmidtbauer in project SD2 at a SIMULINK experiment being set up in 2000 at Chalmers Mechatronics

Simulation of stop braking, drag braking and complete braking programs (sequences recorded in-field) is performed in an outdoor environment. Disk brakes and block brakes with a maximum wheel diameter of 1500 mm can be handled. An electric motor of maximum power 250 kW drives 2 to 12 flywheels, each at 630 kg and 267 kgm^2, with a maximum speed of 1500 rpm

The brake test rig (inertia dynamometer) at Surahammar (used in projects SD1, SD4, EU1 and EU8) at its inauguration in 1989. From the left: Roger Lundén, Josef Rauch (from Sura Traction, now Lucchini Sweden), Bengt Åkesson, Elisabet Lundqvist and Lennart Nordhall (both from Sura Traction), Mikael Fermér (from Chalmers Solid Mechanics), and Nils Månsson and Sven A Eriksson (both from SJ Machine Division)

Parameters controlled
Braking air pressure (max 5 bar)
Train speed (max 250 km/h)
Axle load (max 30 tonnes)
Environment (heat, cold, water, snow...)

Results recorded
Braking moment
Temperatures
Strains and stresses
Wear

Design for two extreme stop braking cases:

$2m$ tonnes	v_0 km/h	s_{sign} m	s_b m	t_b s	r m/s^2	Q_0 kW	E kWh	D m	n rpm	M Nm
30	140	1000	772	39.7	0.98	571	3.15	0.92	807	6760
16	250	3500	2837	81.7	0.85	472	5.36	0.88	1500	2990

SD3. COMPUTER CONTROL OF BRAKING SYSTEMS FOR FREIGHT TRAINS

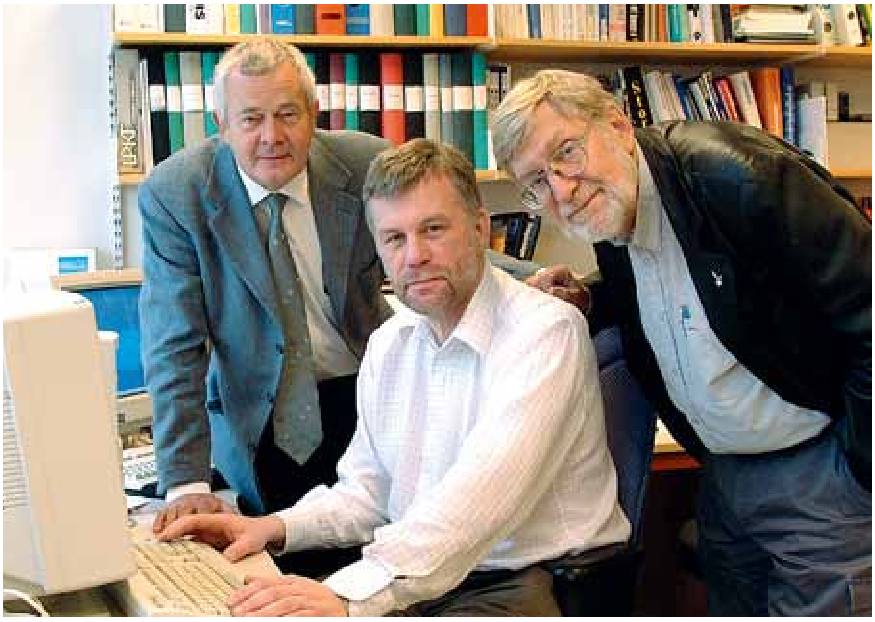
Datorstyrning av bromsar till godståg
Rechnersteuerung der Bremssysteme von Güterzügen
Contrôle par ordinateur des systèmes de freinage de trains fret

The SD3 project was completed with Roger Johansson's successful defence in public of his doctoral dissertation in June 2005. The faculty-appointed external examiner of the dissertation was Professor Martin Törngren from the Division of Mechatronics in the Department of Machine Design at the Royal Institute of Technology (KTH) in Stockholm, Sweden. The title of the dissertation is "On distributed control-by-wire systems for critical applications". The research in project SD3 was led by Mr Håkan Edler, MSc, and scientifically supervised by Professor Jan Torin of Chalmers Computer Science and Engineering.

Computers are being used to control processes of the most varying types and the applications are often spread over several computers in a network. Each computer can then be placed close to sensors and actuators to gather data and process them close to sources and sinks. Traditional electrical and mechanical interfaces can be replaced by data communication in the networks. Such distributed real-time systems provide many advantages in terms of speed, flexibility and safety/security. One example is train brakes, where a distributed computer system can give shorter response times and better means of controlling braking processes than pneumatic systems.

An important issue in project SD3 was how to achieve a satisfactory level of safety with the then commercially available technology. Ways were found to construct reliable systems with the help of computer software, and methods were developed for verifying the reliability of these systems. A simple and robust electronic system as an add-on to the existing control system was designed and constructed.

The reference group for project SD3 included members from Faiveley Transport, Green Cargo, Halmstad University (Sweden) and SP Technical Research Institute of Sweden. See also CHARMEC's Triennial Reports for Stages 2, 3 and 4.



PhD student Roger Johansson (centre; doctorate earned in June 2005) and his project leader Mr Håkan Edler (left) and supervisor Professor Jan Torin in project SD3. Photo taken in 2003

SD4. CONTROL OF BLOCK BRAKING

Reglering av blockbromsning
Steuerung von Klotzbremsen
Contrôle du freinage à sabot

The SD4 project was completed with Tore Vernersson's successful defence in public of his doctoral dissertation in June 2006. The faculty-appointed external examiner of the dissertation was Professor Andrew Day from the School of Engineering, Design & Technology at the University of Bradford in West Yorkshire, UK (same as for project SD1). The title of the dissertation is "Tread braking of railway wheels – noise-related tread roughness and dimensioning wheel temperatures". Professor Roger Lundén of Chalmers Applied Mechanics supervised the research in project SD4.

Project SD4 aimed to improve knowledge and control of the heat distribution between block and wheel with a focus on wheel behaviour. Thermal phenomena were studied for various braking histories using computer simulations together with experimental data for forged wheels on the Lucchini / CHARMEC inertia dynamometer at Surahammar.

The tendency of cast-iron brake blocks to generate high roughness levels on wheel treads has propelled a general shift in the railway industry to other materials that do not generate disturbing roughness levels. However, this change of block material affects the heat partitioning between wheel and block. It was observed in project SD4 that excessive heating of the wheel may cause damage and result in problems with axial deflection of the wheel rim (change of wheelset gauge), and that high tensile stresses in the wheel rim after its cooling down can lead to the initiation and growth of transverse cracks on the running surface. A thermal model of railway tread braking was developed for use in design calculations (continued in project SP15) of wheel and block temperatures, including the cooling influence from the rail, so-called rail chill. The rail chill was found to have a considerable influence on the wheel temperature for long brake cycles.

Photo of an experimental test set-up at Surahammar with a tread-braked wheel in rolling contact with a "rail-wheel". One slotted composition block (configuration 1Bg) is used, see figure on page 81

A general observation in project SD4 was that the stiffness of the brake block support is important for wheel behaviour during a brake cycle. A stiff support together with a stiff block material (such as cast iron or sinter material) will make both the axial rim deflections and rim temperatures oscillate due to an unstable thermoelastic interaction between the block(s) and the wheel tread. A more flexible mounting was found to eliminate these phenomena.

Field test campaigns were run on the Velim test track in the Czech Republic and on the Coal Link in the Republic of South Africa. See also CHARMEC's Triennial Reports for Stages 3, 4 and 5. The reference group for project SD4 included members from SAB WABCO / Faiveley Transport and Interfleet Technology.

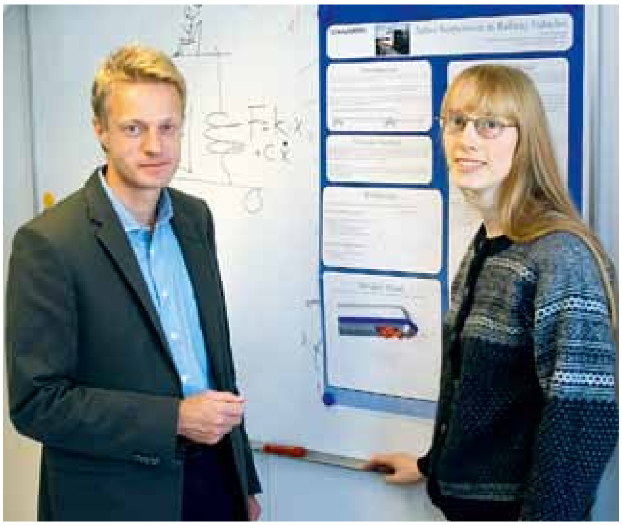
Dr Tore Vernersson (left; doctorate earned in June 2006), his co-worker Mr Hans Johansson (centre), Research Engineer, and his supervisor Professor Roger Lundén in project SD4. Photo taken in 2006

SD5. ACTIVE AND SEMI-ACTIVE SYSTEMS IN RAILWAY VEHICLES

Aktiva och semiaktiva system i järnvägsfordon
Aktive und halbaktive Systeme in Eisenbahnfahrzeugen
Systèmes actifs et semi-actifs dans des véhicules ferroviaires

A mathematical model of a railway car has been built by doctoral candidate Jessica Fagerlund using the MultiBody System (MBS) software SIMPACK to study a possible active control of the vertical secondary suspension. Track irregularities were imported to the model and simulations were performed. The resulting car body accelerations and deflections were studied as well as different ride indices. As an alternative to SIMPACK, the general computer program MATLAB was also used in the modelling work. Professor Jonas Sjöberg from Chalmers Signals and Systems together with Professor Thomas Abrahamsson from Chalmers Applied Mechanics supervised the research in project SD5. The direct engagement and financial support by CHARMEC in this project was terminated on 30 June 2007.

The reference group for project SD5 included members from Banverket, Bombardier Transportation Sweden, Interfleet Technology and KTH Railway Group. See also CHARMEC's Triennial Reports for Stages 3, 4 and 5. Jessica Fagerlund presented her licentiate thesis at a seminar on 8 June 2009 and Dr Anna-Karin Christensson from University West in Trollhättan (Sweden) introduced the discussion. The title of the thesis is "Towards active car body suspension in railway vehicles".



PhD student Jessica Fagerlund (licentiate gained in June 2009) and her supervisor Professor Jonas Sjöberg in project SD5. Photo taken in 2006

SD6. ADAPTRONICS FOR BOGIES AND OTHER RAILWAY COMPONENTS

Adaptronik för boggier och andra järnvägskomponenter
Adaptronik für Drehgestelle und andere Komponenten der Eisenbahn
Adaptronique pour des bogies et d'autres composants de chemin de fer

Project leaders and supervisors	Professor Viktor Berbyuk and Docent (now Professor) Mikael Enelund, Applied Mechanics / Division of Dynamics
Doctoral candidate	Mr Albin Johnsson (from 2008-03-03; Lic Eng February 2011)
Period	2008-03-01 – 2011-06-30
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 1000 + 200 Stage 6: kSEK 935
Industrial interests in-kind budget	Stage 5: – Stage 6: kSEK 200 *(Bombardier Transportation)*

The project was financed by Family Ekman's Research Donation (through CHARMEC's budget)

Active components are becoming accepted for railway vehicles and the improved suspension performance thereby being introduced will result in a better ride quality in passenger trains. Even more important is the ability to operate trains at higher speeds on existing tracks while maintaining the same ride quality as before. In some cases, both tilting and active secondary suspension (lateral and/or vertical) will be needed. In railway engineering, the potential to simultaneously increase operational train speed, improve ride comfort and minimize safety risks and maintenance costs drive the adaptronics area. Semi-active and active technologies and different control strategies have been studied in project SD6. Hardware components of special interest were electromechanical elements and Magneto-Rheological (MR) dampers.

Multi-objective optimization has been used in the project to find the best combinations of damping parameters for the primary and secondary bogie suspensions. Performance objectives for safety, ride quality and wear were introduced and results presented in terms of Pareto fronts

SD6. (cont´d)

PhD student Albin Johnsson (middle; licentiate gained in February 2011) and his supervisors Professor Viktor Berbyuk (left) and Docent (now Professor) Mikael Enelund from project SD6. Photo taken in 2009. For a more recent photo of Viktor Berbyuk and Mikael Enelund, see page 82

(trade-off curves in the performance objective space) as well as Pareto sets (trade-off curves in the design parameter space). These curves provide valuable information for choosing an optimal setting.

The damping characteristics of the primary and secondary suspensions were found to have a significant impact on the dynamic behaviour of the railway vehicle. Sensitivity analyses demonstrate the dependency of the safety-comfort Pareto front on train speed, see figure. It was also shown that the quality of wheel and rail profiles has a large impact on the vehicle dynamics. Adaptive control strategies for the primary and secondary suspension dampings of the bogie under different ride conditions were outlined.

Albin Johnsson presented his licentiate thesis (see below) at a seminar on 24 February 2011 where Professor Sebastian Stichel of the Royal Institute of Technology (KTH) in Stockholm acted as discussion initiator. Albin Johnsson left Chalmers at the end of March 2011 to take up employment with the consultancy Xdin AB in Gothenburg.

The research plan for project SD6 is dated 2008-03-01. The joint reference group for projects TS12 and SD6 consisted of members from Bombardier Transportation Sweden and Interfleet Technology. Work in the same area as in project SD6 continues in the new project SD9.

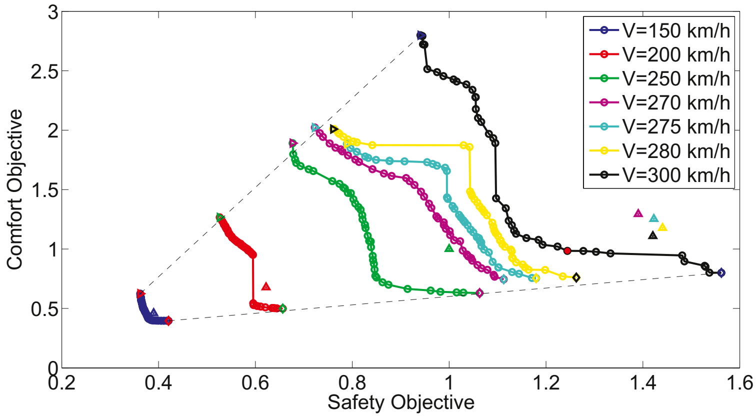
Albin Johnsson, Viktor Berbyuk and Mikael Enelund: Optimized bogie system damping with respect to safety and comfort, *Proceedings 21st International Symposium on Dynamics of Vehicles on Roads and Tracks (IAVSD'09),* Stockholm August 2009, 12 pp (documented on CD)

Albin Johnsson, Viktor Berbyuk and Mikael Enelund: Vibration dynamics of high speed train with Pareto optimized damping of bogie system to enhance safety and comfort, *Proceedings ISMA2010 International Conference on Noise and Vibration Engineering,* Leuven (Belgium) September 2010, pp 3477-3488 (documented on CD)

Albin Johnsson, Viktor Berbyuk and Mikael Enelund: Vibrationsdynamik hos höghastighetståg med Pareto-optimerad dämpning i boggiupphängningen för att förbättra säkerhet och komfort (Vibrational dynamics of high-speed trains with Pareto-optimized damping in bogie suspension to improve safety and comfort; in Swedish), *16th Nordic Seminar on Railway Technology,* Nynäshamn (Sweden) September 2010, 1+28 pp (Summary and PowerPoint presentation). Documented on CD)

Albin Johnsson: Multi-objective optimization of railway bogie suspension damping, Licentiate Thesis, *Chalmers Applied Mechanics*, Gothenburg February 2011, 76 pp (Summary and three appended papers)

Albin Johnsson, Viktor Berbyuk and Mikael Enelund: Pareto optimization of railway bogie suspension damping to enhance safety and comfort, *Vehicle System Dynamics,* 2012, vol 50, no 9, 2012, pp 1379–1407



Example of calculated Pareto fronts in project SD6

SD7. THERMAL CAPACITY OF TREAD BRAKED RAILWAY WHEELS

Termisk kapacitet hos blockbromsade järnvägshjul
Thermische Kapazität von Eisenbahnrädern mit Klotzbremsen
Capacité thermique des roues ferroviaires avec freins à sabot

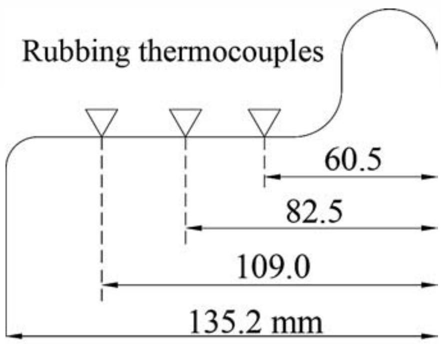
Project leaders and supervisors	Professor Roger Lundén and Dr Tore Vernersson, Applied Mechanics / Division of Dynamics
Doctoral candidate	Mr Shahab Teimourimanesh (from 2008-09-22; Lic Eng February 2012)
Period	2008-09-01 – 2012-06-30 (–2013-09-30)
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 600 Stage 6: kSEK 2900 Stage 7: kSEK 1550
Industrial interests in-kind budget	Stage 5: kSEK 100 + 300 + 50 + 200 Stage 6: kSEK 100 + 300 + 50 + 400 Stage 7: kSEK 50+100+25+50 *(Bombardier Transportation + Faiveley Transport + Interfleet Technology + Lucchini Sweden)*

For a photo, see under project SD8

The thermal capacity of the wheels puts a limit to railway tread braking systems. In project SD7, the range of applications varies from light, medium and heavy metros to mainline coaches and freight locomotives, however the focus is on wheels for metros where frequent stop braking occurs. Except for the drag braking cases described in the European standard EN 13979-1, there are no known standards in the public domain relating to the thermal capacity limits for wheels. In-service rejection criteria (e g, maximum residual stress levels and wheelset gauge changes) for wheels that have endured a (potential) overheating event also require consideration. The present project develops methods and provides data that can form a basis for future design guidelines.

Results from the previous project SD4 on the heat partitioning between brake block, wheel rim and rail are being used, and a new broad parametric study has been carried out to investigate the influence of brake block materials, brake pressure distributions and external thermal conditions. The numerical analysis showed that hot spots in the block–wheel contact have a major impact on local temperatures but only a minor influence on the global heat partitioning in the wheel-block-rail system. A presumed constant axial position of the wheel–rail contact towards the flange side of the tread was found to lead to substantially higher maximum tread temperatures than a wheel–rail contact centred at the brake block position. Shahab Teimourimanesh took part in brake rig experiments performed in April 2009 with Federal Mogul Corporation at Chapel-en-le-Frith in Derbyshire (UK) and also in a field test campaign run in May 2010 in Shanghai (China), where wheel and brake block temperatures were measured during different service conditions on a metro line.

Shahab Teimourimanesh presented his licentiate thesis (see below) at a seminar on 23 February 2012 with Docent



Embedded (three in wheel web and four in brake block) and rubbing (three on wheel tread surface) thermocouples used in brake rig experiments by Faiveley Transport together with Federal Mogul Corporation and CHARMEC in April 2009 at Chapel-en-le-Frith, UK

Shanghai metro train in the field test campaign of project SD7 in May 2010 (photo by Markus Meinel of Faiveley Transport Nordic)

Ulf Sellgren of KTH Machine Design introducing the discussion. Thereafter, project SD7 has shifted its focus from the temperature problem to the thermally induced stresses. The research plan for project SD7 is dated 2006-12-15. The joint reference group for projects SD7 and SD8 has members from Bombardier Transportation (in Siegen/Germany, Sweden and UK), Faiveley Transport, Interfleet Technology and SL.

Shahab Teimourimanesh, Roger Lundén and Tore Vernersson: Braking capacity of railway wheels – state-of-the-art survey, *Proceedings 16th International Wheelset Congress (IWC16)*, Cape Town (RSA) March 2010, 18 pp (documented on USB)

Shahab Teimourimanesh, Roger Lundén and Tore Vernersson: Tread braking of railway wheels – state-of-the-art survey, *Proceedings 6th European Conference on Braking (JEF 2010) / 6ème Conférence Européenne du Freinage)*, Lille (France) November 2010, pp 293-302

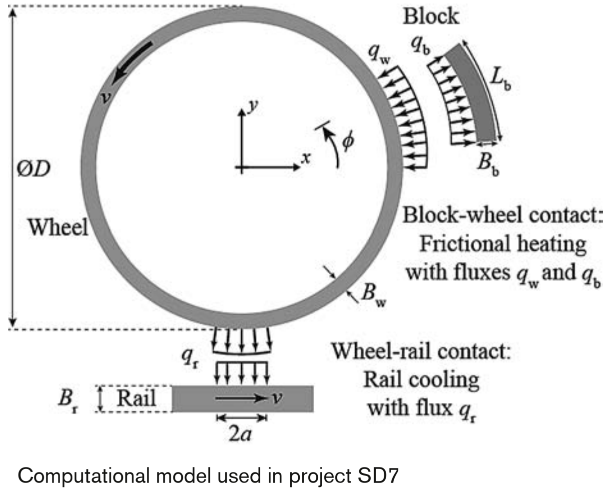
Shahab Teimourimanesh, Roger Lundén and Tore Vernersson: Thermal capacity of tread braked wheels, *16th Nordic Seminar on Railway Technology,* Nynäshamn (Sweden) September 2010, 1+26 pp (Summary and PowerPoint presentation. Documented on CD)

Shahab Teimourimanesh: Railway tread braking temperatures – numerical simulation and experimental studies, Licentiate Thesis, *Chalmers Applied Mechanics,* Gothenburg February 2012, 74 pp (Summary and three appended papers)

Saeed Abbasi, Shahab Teimourimanesh, Tore Vernersson, Ulf Sellgren, Ulf Olofsson and Roger Lundén: Temperature and thermoelastic instability of tread braking friction materials, *Proceedings 9th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2012)*, Chengdu (China) August 2012, pp 606-607

Shahab Teimourimanesh, Tore Vernersson, Roger Lundén, Fredrik Blennow and Markus Meinel: Tread braking of railway wheels – temperatures generated by a metro train, *IMechE Journal of Rail and Rapid Transit* (accepted for publication)

Shahab Teimourimanesh, Tore Vernersson and Roger Lundén: Modelling of temperatures during railway tread braking – influence of contact conditions and rail cooling effect, *IMechE Journal of Rail and Rapid Transit* (accepted for publication)



Computational model used in project SD7

SD8. WEAR OF DISC BRAKES AND BLOCK BRAKES

Slitage hos skivbromsar och blockbromsar
Verschleiss von Scheibenbremsen und Klotzbremsen
Usure des freins à disque et des freins à sabot

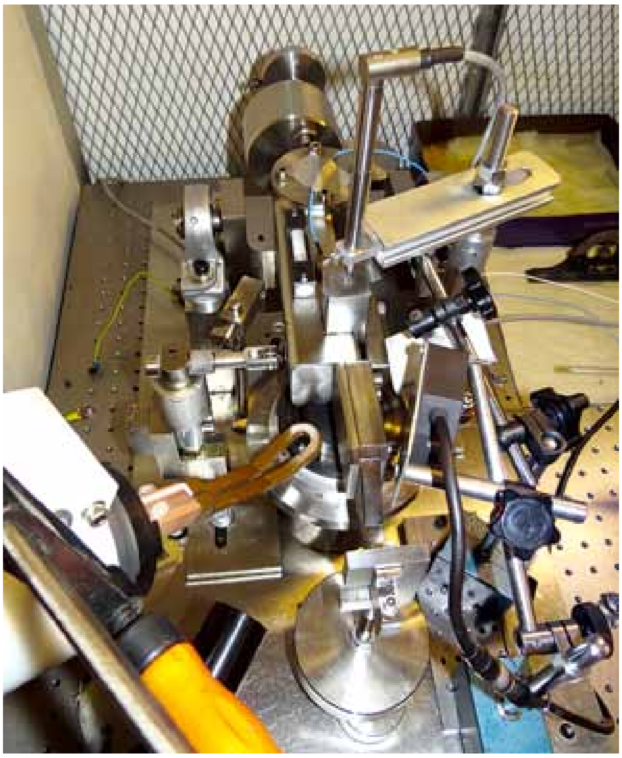
Project leader	Dr Tore Vernersson, Applied Mechanics / Division of Dynamics
Co-worker	Professor Roger Lunden, Applied Mechanics
Doctoral candidate	None (only senior researchers in this project)
Period	2008-01-01 – 2012-06-30
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 1200 Stage 6: kSEK 950
Industrial interests in-kind budget	Stage 5: kSEK 200 Stage 6: kSEK 200 *(Faiveley Transport)*

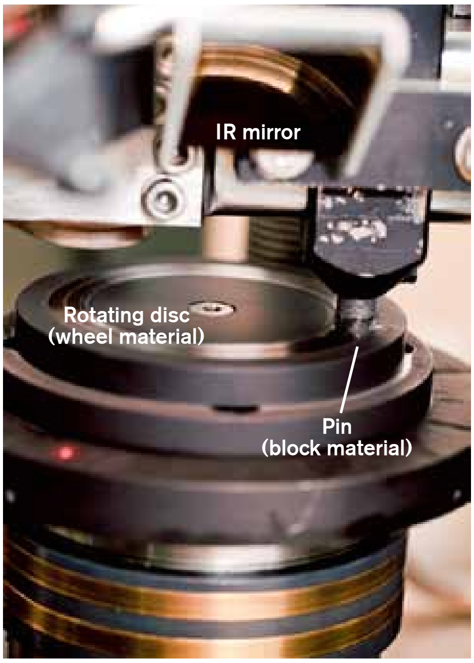
For a photo of Tore Vernersson and Roger Lundén, *see page 75*

As observed in revenue operations, the main part of the life cycle cost of a braking system is related to the wear of the brakes, since this determines the time intervals between calls for maintenance at a workshop. In project SD8, a comprehensive study of the thermomechanical interaction and wear in disc brakes and block brakes has been carried out. Here, the properties of friction materials in brake pads and brake blocks, with their often complex dependence on, e g, temperature and pressure, are important. So are also the geometrical design and mechanical stiffness of the interacting brake components since they determine the movements of pads and blocks. The brake design thus controls both the deformations due to static brake loads and the thermal deformations due to temperature gradients and temperature differences in the components.

The overall aim of project SD8 was to reduce weights and life cycle costs, and to improve braking performance. Mathematical and numerical models have been developed and calibrated to data from laboratory experiments and field studies. The models deliver the total amount of wear of pads and blocks for a train in revenue traffic and also the wear variation both temporally and spatially. Ultimately, the models should enable an optimization of the full brake system for minimization of wear and hence of the maintenance costs. Flytoget in Norway and SL Metro C20 together with the X10p train on Roslagsbanan in Stockholm were chosen as reference cases for axle-mounted disc brakes and tread brakes, respectively.

Laboratory studies of the wear of friction materials have been performed in co-operation with the KTH Department of Machine Design. Here, a novel set-up was used in a pin-on-disc tester employing an external induction heating system to control the disc temperature. The temperature dependence of the wear was investigated for constant disc temperatures of up to 600 °C. For three





Part of equipment used in experiments at KTH. Rotating disc with pin is seen in the middle with induction heater in front of it. Detail with disc and pin above

PhD student Shahab Teimouri-manesh (left; licentiate gained in February 2012) of project SD7 together with Dr Tore Vernersson (second from the left) and Professor Roger Lundén (right), both active in the two projects SD7 and SD8. The fourth person is PhD student Gaël Le Gigan who works in an associated project with VINNOVA and Scania AB on disc brakes for trucks, see page 119. Studied are a rubbing thermocouple, a railway brake block and a truck brake disc

organic composite materials, the wear rate was found to smoothly increase with temperature up to a critical level of about 500 °C, after which a radical increase was observed. For a cast iron material, the wear rate was also found to increase with temperature up to 500 °C, but after that a transition could be observed, resulting in a drastic decrease of the friction coefficient in parallel with a decrease of the wear rate. A hypothesis is that this transition is linked to a build-up of stable oxides on the pin contact surface at temperatures higher than 500 °C. For a sinter material, the experiments indicated a slight trend towards increased wear rate with increasing temperature.

The wear resulting from a single stop braking cycle on a route containing multiple sequential brake cycles has been numerically studied using a temperature-dependent wear model. It was found that a high mounting stiffness may cause the frictional contact to be localized towards one of the edges of the brake block and brake pad, and that such a brake cycle may double the amount of wear compared to a brake cycle which has a more conformal contact (which is the case when using a low mounting stiffness). The wear on generic routes containing 30 stops has been studied for varying distances between stations and with different braking efforts. The resulting contact pressures, temperature levels and wear rates are reported in the below references.

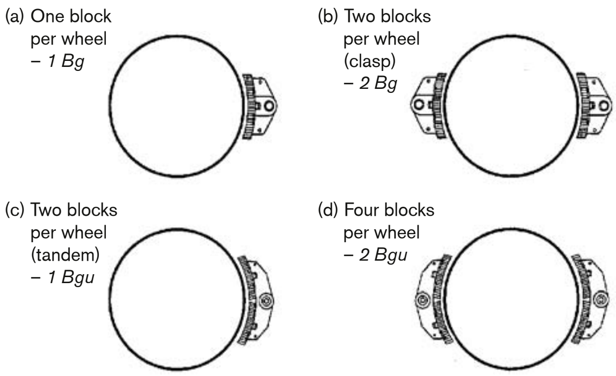
The joint reference group for projects SD7 and SD8 has members from Bombardier Transportation (Siegen/Germany, Sweden and UK), Faiveley Transport, Interfleet Technology and SL. The research plan for project SD8 is dated 2007-05-18.

Tore Vernersson and Roger Lundén: Wear of disc brakes and block brakes – influence of design on modelled wear for repeated brake cycles, *Proceedings 16th International Wheelset Congress (IWC16)*, Cape Town (RSA) March 2010, 16 pp (documented on CD)

Tore Vernersson and Roger Lundén: Wear of block brakes and disc brakes for repeated brake cycles, *Proceedings 6th European Conference on Braking (JEF 2010)* / 6èmes Journées Européennes du Freinagee), Lille (France) November 2010, pp 19-27

Tore Vernersson, Roger Lundén, Saeed Abbasi and Ulf Olofsson: Wear of railway brake block materials at elevated temperatures – pin-on-disc experiments, *Proceedings EuroBrake 2012 Conference,* Dresden (Germany) April 2012, 11 pp (documented on USB stick)

Tore Vernersson and Roger Lundén: Wear of brake blocks for in-service conditions, *Proceedings 9th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2012),* Chengdu (China) August 2012, pp 706-713



Four common brake block arrangements. Two blocks can be used in either (b) clasp or (c) tandem arrangements. Bg and Bgu stand for “Bremsklotz geteilt” and “Bremsklotz geteilt underteilt” (German terms)

SD9. MULTIOBJECTIVE OPTIMIZATION OF BOGIE SYSTEM AND VIBRATION CONTROL

Flermålsoptimering av boggisystem och vibrationskontroll
Optimierung von Drehgestellsystem unter mehrfacher Zielsetzung und Schwingungskontrolle
Optimisation par objectifs multiples du système de bogie et conrtrôle des vibrations

Project leaders and supervisors	Professor Viktor Berbyuk and Professor Mikael Enelund, Applied Mechanics / Division of Dynamics
Doctoral candidate	Mr Milad Mousavi, MSc (from 2011-11-01)
Period	2011-07-01 – 2012-06-30 (2016-10-31)
Chalmers budget (excluding university basic resources)	Stage 6: kSEK 865 Stage 7: kSEK 2790
Industrial interests in-kind budget	Stage 6: – Stage 7: kSEK 200 *(Bombardier Transportation)*

The project is financed by Family Ekman's Research Donation (through CHARMEC's budget)

The bogie system transmits forces between train and track. With increasing requirements on the performance of railway vehicles, the demands on their bogies will also increase. Not only need the bogie be "stiff" enough to guarantee the stability of the running vehicle but it should also be "soft" enough to ensure passenger comfort and minimize rolling contact wear and fatigue of rails and wheels. These demands on bogies are becoming difficult to meet by use of traditional passive solutions, a fact which has led to an acceptance of active components. In project SD9, the focus is on a combination of multi-objective optimization of the bogie system and active vibration control. In addition, appropriate actuation technologies should be developed.

The main aims and objectives of project SD9 are: (i) to formulate and solve multi-objective optimization problems for a multidimensional non-linear controlled dynamic system, which models the bogie of a modern railway vehicle with adaptronic components (sensors, actuators and controllers), (ii) to search for the optimal properties of the bogie system by identifying and analysing optimal design parameters, (iii) to study smart-material-based actuator and sensor technology to get an insight into the expected outcome of their application to bogie systems for high-speed railway vehicles, and (iv) to design adaptive strategies for optimal vibration control and system stability of the complete vehicle.

This project continues the research started in project SD6 and a new doctoral candidate has been engaged, see above. He has started investigating engineering, mathematical and computational models of bogie systems with different levels of complexity. Viktor Berbyuk and Milad Mousavi discussed the project with Henrik Tengstrand, Rickard Persson and Jakob Wingren of Bombardier Transportation Sweden in Västerås on 27 April 2012.

The reference group for project SD9 has members from Bombardier Transportation, Interfleet Technology, Trafikverket and KTH Railway Group. The research plan for the project is dated 2011-04-28.

PhD student Milad Mousavi (left) and his supervisors Professor Viktor Berbyuk (right) and Professor Mikael Enelund from project SD9

EU1. EUROSABOT

EuroSABOT – Sound attenuation by optimised tread brakes
Schallverminderung durch optimierte Klotzbremsen
Atténuation du bruit par l´optimisation des freins à sabot

For a photo of project leader Roger Lundén and his co-worker Hans Johansson, see page 75

EuroSABOT had a total budgeted project cost of KEUR 3724 and budgeted EU funding of KEUR 1858. Chalmers/CHARMEC's share of the EU funding was KEUR 164 and our commitment to the project was 13 man-months. EuroSABOT ran between 1 March 1996 and 31 August 1999. The project was co-ordinated by AEA Technology Rail BV (Paul de Vos).

Tread-braked railway vehicles radiate a high rolling sound caused by the fact that brake blocks generate roughness (waviness, corrugation) on the wheel tread, which induces vibrations and noise. The aim of EuroSABOT and project EU1 was to develop new and better brake blocks that caused less roughness on the wheel tread than cast-iron blocks. CHARMEC's work was carried out in close collaboration with project VB2. A great deal of experimental work was done on the brake rig (inertia dynamometer) at Surahammar (now Lucchini Sweden) where our Hans Johansson assisted, see page 73.

Professor Roger Lundén led project EU1. See also CHARMEC's Triennial Report for Stage 2.

Photo of a cast-iron brake block in operation on the test rig at Surahammar in projects SD1 and EU1

EU2. SILENT FREIGHT

Silent Freight – Development of new technologies for low noise freight wagons
Entwicklung neuer Technologien für leise Güterwagen
Développement de nouvelles technologies pour des wagons fret silencieux

For a photo of project leader Jens Nielsen, see page 17

Silent Freight had a total budgeted project cost of KEUR 3196 and budgeted EU funding of KEUR 1700. Chalmers/CHARMEC's share of the EU funding was KEUR 91 and our commitment to the project was 17 man-months. Silent Freight ran between 1 February 1996 and 31 December 1999. The project was co-ordinated by ERRI (William Bird).

The objective of Silent Freight and the EU2 project was to reduce the noise level of rolling stock used in freight traffic by 10 dB(A). CHARMEC's contribution was to investigate whether a proposal put forward by us for a standard wheel with a perforated wheel disc could be a cost-effective solution, and applicable on existing types of freight wagon wheels.

The sound radiation from prototypes of perforated wheels was calculated with the commercial computer program SYSNOISE and measured in the test rig at Surahammar. The outcome of the EU2 project was that acoustic short-circuiting (between the front and rear sides of the vibrating wheel disc) via suitable holes is effective for a frequency range of up to about 1000 Hz. A prototype wheelset manufactured by Adtranz Wheelset (now Lucchini Sweden) was used in the final field tests at Velim in the Czech Republic in May-June 1999.

Docent (now Professor) Jens Nielsen led the EU2 project. See also CHARMEC's Triennial Report for Stage 2.

Computer model of the perforated wheel in project EU2. The wheel was studied both numerically and experimentally

EU3. SILENT TRACK

Silent Track – Development of new technologies for low noise railway infrastructure
Entwicklung neuer Technologien für leise Eisenbahninfrastruktur
Développement de nouvelles technologies pour des infrastructures ferroviaires silencieuses

For a photo of project leader Jens Nielsen, see page 17

Silent Track had a total budgeted project cost of KEUR 3747 and budgeted EU funding of KEUR 2075. Chalmers/CHARMEC's share of the EU funding was KEUR 150 and our commitment to the project was 28.5 man-months. Silent Track ran between 1 January 1997 and 29 February 2000. The project was co-ordinated by ERRI (William Bird).

The aim of Silent Track and project EU3 was to reduce the noise level from tracks with freight traffic by 10 dB(A). CHARMEC's contribution was to further develop the DIFF model (see project TS1) in order to study the origin of corrugation on the railhead, and to propose a new sleeper with reduced radiated sound power. A simulation of corrugation growth in DIFF was calibrated and verified against measurements of wave formation on rails used on Dutch railways. In collaboration with Abetong Teknik (a subcontractor in Silent Track), new optimized two-block sleepers were developed and manufactured, and were also used in the full-scale tests at Velim in the Czech Republic in May-June 1999.

Docent (now Professor) Jens Nielsen led project EU3. See also CHARMEC's Triennial Reports for Stages 2 and 3.

Parallel EU projects – Parallella EU-projekt – Parallele EU-Projekte – Projets parallèles avec l'UE

EU4. ICON

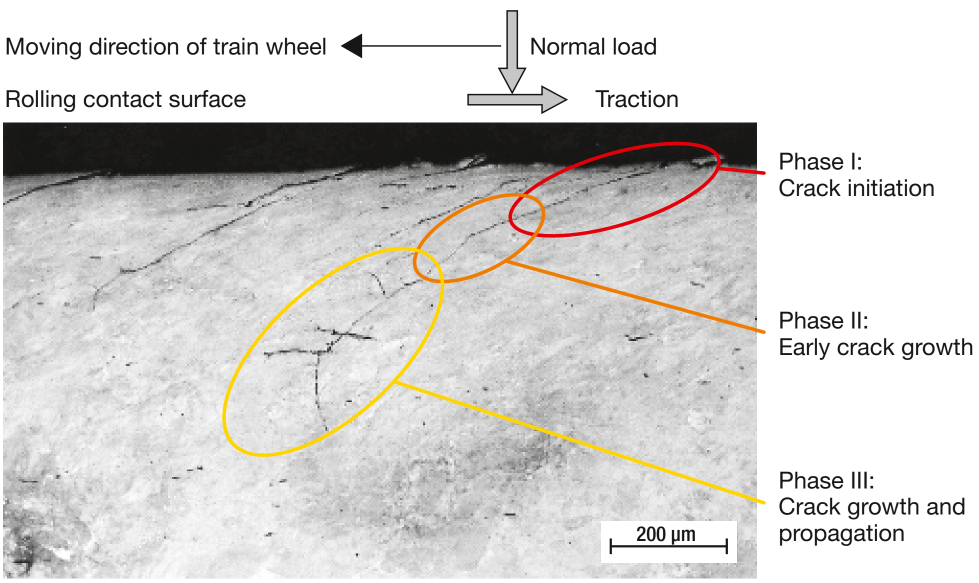
ICON – Integrated study of rolling contact fatigue
Integrierte Studie über Ermüdung durch Rollkontakt
Étude intégrée de la fatigue due au contact roulant

For a photo of project leader Lennart Josefson, see page 41

ICON had a total budgeted project cost of KEUR 1832 and budgeted EU funding of KEUR 1300. Chalmers/CHARMEC's share of the EU funding was KEUR 96 and our commitment to the project was 16 man-months. ICON ran between 1 January 1997 and 31 December 1999. The project was co-ordinated by ERRI (David Cannon).

The aim of ICON and project EU4 was to develop and verify a calculation model that would describe the initiation and early growth of cracks on the railhead. The activities in projects EU4 and MU6 were closely co-ordinated, see under the latter project.

Professor Lennart Josefson led project EU4. See also CHARMEC's Triennial Report for Stage 2.



Three phases of crack development in the railhead under rolling contact load as simulated in a so-called twin disc laboratory experiment in project EU4. The experiment was performed at the Otto-von-Guericke University in Magdeburg, Germany

Parallel EU projects – Parallella EU-projekt – Parallele EU-Projekte – Projets parallèles avec l´UE

EU5. EUROBALT II

EUROBALT II – European research for an optimised ballasted track
Europäische Forschung zur Optimiering von Gleisen auf Schotter
Recherche européenne pour l'optimisation des voies ferrées ballastées

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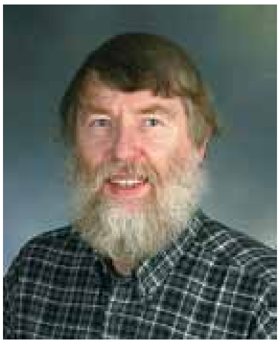
For a photo of project leader Roger Lundén, see page 75

EUROBALT II had a total budgeted project cost of KEUR 4154 and budgeted EU funding of KEUR 2320. Chalmers/CHARMEC's share of the EU funding was KEUR 207 and our commitment to the project was 34 man-months. EUROBALT II ran between 1 September 1997 and 31 August 2000. The project was co-ordinated by SNCF (Jean-Pierre Huille).

CHARMEC's task in the EU5 project was to develop a calculation model that would reproduce and predict the dynamic interaction between the train and the ballasted track. In an introductory literature study, over 1000 references to ballast were identified. Our DIFF calculation model was expanded, see project TS1. A resonance frequency between 20 and 30 Hz in the ballast/subgrade was included.

Professor Tore Dahlberg and Professor Roger Lundén led the EU5 project. See also CHARMEC's Triennial Reports for Stages 2 and 3.



Project leader for EU5, Professor Tore Dahlberg of Linköping Institute of Technology (formerly at Chalmers)

Parallel EU projects – Parallella EU-projekt – Parallele EU-Projekte – Projets parallèles avec l´UE

EU6. HIPERWHEEL

HIPERWHEEL – Development of an innovative high-performance railway wheelset
Entwicklung eines innovativen leistungsstarken Radsatzes
Développement d'un essieu monté innovant à haute performance

For photos of project leader Roger Lundén and his co-workers Jens Nielsen and Anders Ekberg, see pages 23 and 70

The HIPERWHEEL project of the Fifth Framework Programme comprised a total of 280 man-months, a budgeted project cost of KEUR 3690 and budgeted EU funding of KEUR 1979. Chalmers/CHARMEC's share of the EU funding was KEUR 141 and our commitment to the project was 13 man-months. HIPERWHEEL ran between 1 April 2000 and 30 September 2004. The project was co-ordinated by Centro Ricerche Fiat (Kamel Bel Knani).

Outstanding safety, lower weight, longer maintenance intervals and less noise radiation were properties of future wheelsets that the HIPERWHEEL project aimed to attain. CHARMEC's main responsibility was to study damage mechanisms in collaboration with the University of Sheffield and to act as task leader for "Numerical procedure for NVH analysis" (Work Package WP5). CHARMEC also contributed with work in WP3 "Damage mechanisms acting on the wheelset and database for fatigue life prediction" and WP4 "CAE-based procedure for wheelset durability assessments".

One result of HIPERWHEEL was a new wheelset with 25% lower weight where the disc was made of aluminium and the rim of high-strength steel. Professor Roger Lundén with co-workers Docent (now Professor) Jens Nielsen and Dr (now Docent) Anders Ekberg ran the EU6 project. See also CHARMEC's Triennial Reports for Stages 3 and 4. CHARMEC's European partners in HIPERWHEEL are listed in the latter report.

Please note that for an EU project, the "budgeted project cost" entry on pages 87-91 includes the full costs borne by the industrial partners of the EU project but excludes approximately half of the total costs borne by the university. For projects EU9, EU10, EU12 and EU13, the additional costs at Chalmers are reported as "Budget CHARMEC".

Parallel EU projects – Parallella EU-projekt – Parallele EU-Projekte – Projets parallèles avec l´UE

EU7. INFRASTAR

INFRASTAR – Improving railway infrastructure productivity by sustainable two-material rail development
Verbesserte Produktivität der Eisenbahninfrastruktur durch Entwicklung haltbarer Schienen aus zwei Werkstoffen
Amélioration de la productivité de l´infrastructure ferroviaire par le développement des rails durables composés de deux matériaux

For photos of project leaders Lennart Josefson and Roger Lundén and their co-workers Jens Nielsen, Jonas Ringsberg and Birger Karlsson, see pages 17, 41, 49 and 75

The INFRASTAR project of the Fifth Framework Programme comprised a total of 140 man-months with a budgeted project cost of KEUR 1780 and budgeted EU funding of KEUR 1080. Chalmers/CHARMEC's share of the EU funding was KEUR 181 and our commitment to the project was 20 man-months. INFRASTAR ran between 1 May 2000 and 31 October 2003 and was co-ordinated by AEA Technology Rail (Martin Hiensch).

The aim of the INFRASTAR project was to increase the operational life and reduce the emitted noise of particularly exposed stretches of railway track, such as small-radius curves subject to large traffic volumes and high axle loads. The application of an extra surface layer to the railhead was investigated. The intention was to study two different technologies: the melting of powder onto the surface by means of a laser beam, and the rolling-in of an additional layer of material on the bloom when the rail was manufactured. During the course of the project, however, the latter technology was abandoned. See also project MU7.

Shakedown diagrams and calculations were used to illustrate how the improved performance of a coated rail varies with coating thickness, traction coefficient, contact load position, strength of coating, strength of substrate materials, and strain hardening of the materials. It was shown that two-material rails can be used to prevent rolling contact fatigue and reduce wear in a current train traffic situation.

See also CHARMEC's Triennial Reports for Stages 3 and 4. CHARMEC's European partners in INFRASTAR are listed in the latter report. Professor Lennart Josefson and Professor Roger Lundén with co-workers Docent (now Professor) Jens Nielsen, Dr (later Docent, now Professor) Jonas Ringsberg and Professor Birger Karlsson ran the EU7 project.

Parallel EU projects – Parallella EU-projekt – Parallele EU-Projekte – Projets parallèles avec l´UE

EU8. ERS

ERS – Euro Rolling Silently

For photos of project leader Roger Lundén and his co-workers Martin Helgen, Jan Henrik Sällström and Tore Vernersson, see page 75 in the foregoing and page 89 in the Triennial Report for Stage 4

The ERS (Euro Rolling Silently) project of the Fifth Framework Programme comprised a total of 317 man-months with a budgeted project cost of KEUR 5880 and budgeted EU funding of KEUR 2470. Chalmers/CHARMEC's share of the EU funding was KEUR 206 and our commitment to ERS was 20 man-months. ERS ran between 1 September 2002 and 31 August 2005 and was co-ordinated by SNCF (Jacques Raison).

The aim of the ERS project was to develop new "LL" type brake blocks for tread-braked freight wagons. Without modifying the wagons, the blocks would replace the existing cast-iron blocks of grade P10 (i e, a retrofit solution was requested). CHARMEC's investment in the project was a state-of-the-art description and thermomechanical simulations. The thermomechanical capability of two freight wagon wheels (VMS from Valdunes and RAFIL from Radsatzfabrik Ilsenburg) was evaluated. Temperature results from brake bench tests were used for calibrating axisymmetric finite element models, including both wheel and brake block. Tests performed on the Lucchini / CHARMEC inertia dynamometer at Surahammar included an investigation of the effect of rail chill (cooling of the rolling wheel through its contact with the rail, see project SD4).

For a drag braking rig test with cast-iron brake blocks in 2 Bgu configuration (see figure on page 81), it was found that 70% of the total braking power typically goes as heat into the wheel. With composition brake blocks in 2 Bg configuration, about 95% of the total braking power goes as heat into the wheel.

Professor Roger Lundén with co-workers Mr Martin Helgen (MSc), Docent Jan Henrik Sällström and Mr (now Dr) Tore Vernersson ran the EU8 project. See also CHARMEC's Triennial Reports for Stages 3 and 4. CHARMEC's European partners in ERS are listed in the latter report.

EU9. EURNEX

EURNEX – European Rail Research Network of Excellence

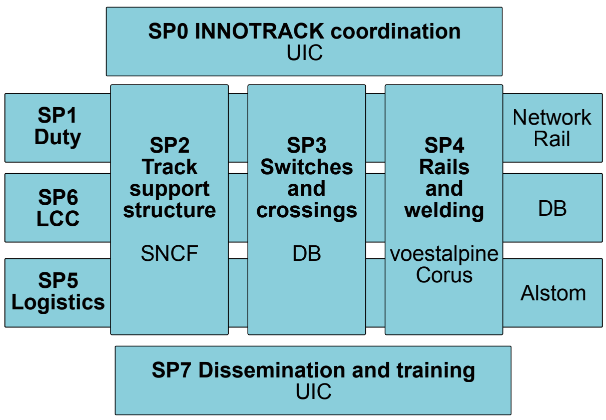
Project leader	Professor Roger Lundén, Applied Mechanics/ Division of Dynamics
Co-worker	Docent Anders Ekberg, Applied Mechanics
Period	2004-01-01 – 2007-12-31 (EU Network of Excellence) 2008-01-01 – 2010-12-31 (EURNEX Association)
Budget EU	Not specified
Budget CHARMEC	Stage 4: – Stage 5: kSEK 150 + kEUR 1.5 × 1.685 Stage 6: kEUR 3 × 1.685

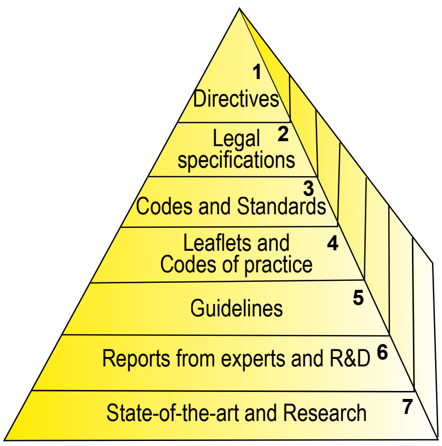
For a photo of Roger Lundén and Anders Ekberg, see page 70

EURNEX is no longer an EU project but the original CHARMEC designation EU9 has been retained. EURNEX was financed during 2004-2007 by the EU under the Sixth Framework Programme, see www.eurnex.net. The EURNEX Association was founded on 30 October 2007 to continue the EURNEX idea. The activities are co-ordinated by FAV in Berlin (FAV stands for Forschungs- und Anwendungsverbund Verkehrssystemtechnik), which also co-ordinated the previous EU project. Chalmers/CHARMEC is currently a member of the EURNEX Association.

According to its Statutes dated 2007-10-30, the objective of the EURNEX Association is to promote research and the development of the rail system, and more specifically to (1) enhance co-operation in research and education as well as knowledge transfer between members of the Association and European Universities and Research Establishments that are interested in railway research, including multidisciplinary capabilities, (2) facilitate the scheduling and implementation of joint research projects between members of the Association and build up a sustainable research environment for the railway sector, (3) develop links between members of the Association, industrial partners and operators within the railway sector, (4) increase awareness of specific high-quality research needs and opportunities for co-operation with the railway sector, (5) promote railway contributions to sustainable transport policy, and (6) improve the competitiveness and economic stability of the railway sector and industry.

As EURNEX (the Network of Excellence) evolved up to 31 December 2007, an organization based on ten "Poles of Excellence" was established. Anders Ekberg was the leader of Pole 8, which dealt with "Infrastructure and Signalling".





INNOTRACK project organization with subprojects and responsible partners, and hierarchy of regulations in the European rail sector. From INNOTRACK Concluding Technical Report

EU10. INNOTRACK

INNOTRACK – Innovative Track Systems

Project leader	Professor Roger Lundén, Applied Mechanics/ Division of Dynamics
Co-workers	Docent Johan Ahlström Dr Mats Ander Mr Jim Brouzoulis, Lic Eng Docent Anders Ekberg Professor Magnus Ekh Docent Elena Kabo Professor Birger Karlsson Docent Fredrik Larsson Dr Anders Johansson Dr Göran Johansson Professor Jens Nielsen Mr Björn Pålsson, Lic Eng Professor Kenneth Runesson Dr Johan Sandström Mr Martin Schilke, Lic Eng Dr Johan Tillberg Professor Bengt Åkesson
Period	2006-09-01 – 2009-12-31 (prolonged to 2012-06-30 without EU funding)
Budget EU	kEUR 560+48+46+9
Budget CHARMEC	Stage 5: kSEK 3415+1 600+330 Stage 6: –

Chalmers / CHARMEC was a partner in INNOTRACK, an Integrated Project (IP) under the Sixth Framework Programme: Thematic Priority 6 – Sustainable Development, Global Change and Ecosystems. The aim of INNOTRACK was to deliver innovative products, processes and methodologies in order to achieve the ERRAC targets of increased quantities and quality of rail transport on conventional lines with mixed traffic. INNOTRACK is said to be the first European project with comprehensive co-operation between infrastructure managers and the supply industry regarding the complete track construction, with the aim to reduce the rate of track degradation and maintenance intervention. INNOTRACK comprised a total of 1 266 man-months with a budgeted project cost of MEUR 18.6 (including budgeted EU funding of MEUR 10.0). The 36 partners (from 10 countries) in INNOTRACK are listed in CHARMEC's Triennial Report for Stage 4. Banverket's (now Trafikverket) Björn Paulsson was the Project Manager, representing the UIC and based in their office in Paris. CHARMEC's Anders Ekberg was the technical and scientific co-ordinator for the entire INNOTRACK project, see page 87.

INNOTRACK's project manager Björn Paulsson (left) and technical and scientific co-ordinator Anders Ekberg outside the UIC office in Paris. Photo taken in 2009

The results of the INNOTRACK project have been reported in 144 "deliverables". CHARMEC was the lead contractor for 6 of these and contributed to others. A Concluding Technical Report (see below and page 117) summarizing the overall results of INNOTRACK has been compiled by us. INNOTRACK formally ended on 31 December 2009 and later activities have focused on dissemination and implementation (see also projects SP21 and SP22). For co-ordination at the European level, an INNOTRACK Implementation Group has been formed with Anders Ekberg participating. He and Björn Paulsson have also participated in the UIC Track Expert Group (TEG) with the dissemination and quality assurance of project results.

The Executive Summary of the INNOTRACK Concluding Technical Report has been translated into German, French, Swedish and Russian with CHARMEC being involved in the translations into Swedish and Russian. Regarding dissemination activities (co-)organized by CHARMEC, we may mention a public seminar on INNOTRACK with emphasis on the work carried out by us at Chalmers on 9 September 2010, a workshop on "Minimum action rules and maintenance limits" at Chalmers on 19-20 October 2010, a workshop on results regarding switches & crossings including a visit to installed demonstrators in Eslöv (Sweden) on 14–15 February 2012, and a press conference at VINNOVA in Stockholm on 9 September 2010. The Europe-wide implementation of the INNOTRACK results is now being monitored in relation to the Concluding Technical Report, which can be downloaded from the project website www.innotrack.eu.

A special issue of IMechE Journal of Rail and Rapid Transit (see below) provides an overview of the scientific aspects of INNOTRACK.

Björn Paulsson and Anders Ekberg: Cutting the life-cycle cost of track, *Railway Gazette International*, vol 166, no 1, 2010, pp 48-52

Jens Nielsen (editor): Recommendation of, and scientific basis for, optimisation of switches & crossings – part 1, INNOTRACK Deliverable 3.1.5, 2009, 30 pp (and 2 annexes, 12+12 pp)

Jens Nielsen (editor): Recommendation of, and scientific basis for, optimisation of switches & crossings – part 2, INNOTRACK Deliverable 3.1.6, 2009, 19 pp (and 3 annexes, 36+10+14 pp)

Anders Ekberg (editor): Recommendation of, and scientific basis for, minimum action rules and maintenance limits, INNOTRACK Deliverable 4.2.6, 2009, 123 pp (and 6 annexes, 9+8+10+9+10+33 pp)

Anders Ekberg (editor): Experience from review work, INNOTRACK Deliverable 7.3.3, 2009, 14 pp (and 3 annexes, 8+4+1 pp)

Anders Ekberg and Björn Paulsson (editors): INNOTRACK Concluding Technical Report, *UIC*, Paris and Gothenburg 2010, 288 pp (separately, the Executive Summary has been translated into French, German, Russian and Swedish)

Anders Ekberg (guest editor): *IMechE Journal of Rail and Rapid Transit, Special Issue on Innotrack - Innovative Track Systems*, vol 224, no F4, 2010, pp 237-335

Anders Johansson: INNOTRACK – Sammanfattning av delprojekten SP3 (Spårväxlar och korsningar) och SP4 (Räler och svetsning) (Summary of the subprojects SP3 (Switches and crossings) and SP4 (Rails and welding); in Swedish), Research Report 2010:2, *Chalmers Applied Mechanics,* Gothenburg 2010, 30 pp

Dirk Nicklisch, Elias Kassa, Jens Nielsen, Magnus Ekh and Simon Iwnicki: Geometry and stiffness optimization for switches and crossings, and simulation of material degradation, *IMechE Journal of Rail and Rapid Transit*, vol 224, no F4, 2010, pp 279-292. Authors received the 2010 SAGE Best Paper Award and the IMechE Railway Division Prize – T A Steward-Dyer /F H Trevithic Prize

Elena Kabo, Anders Ekberg, Peter Torstensson and Tore Vernersson: Rolling contact fatigue prediction for rails and comparison with test rig results, *IMechE Journal of Rail and Rapid Transit,* vol 224, no F4, 2010, pp 303-317 (also listed under project MU22)

The ten INNOTRACK countries

Björn Paulsson and Anders Ekberg: Results to exemplify the joint EU-project INNOTRACK – Innovative Track Systems, *IMechE Journal of Rail and Rapid Transit*, vol 224, no F5, 2010, pp 361-368

Magnus Ekh, Anders Johansson, Dirk Nicklisch and Björn Pålsson: Simulations wheel–rail contact in switches & crossings, *16th Nordic Seminar on Railway Technology,* Nynäshamn (Sweden) September 2010, 1+19 pp (Summary and PowerPoint presentation. Documented on CD)

Jens Nielsen and Anders Ekberg: Acceptance criterion for rail roughness level spectrum based on assessment of rolling contact fatigue and rolling noise, *Wear,* vol 271, nos 1-2, 2011, pp 319-327

Anders Johansson, Björn Pålsson, Magnus Ekh, Jens Nielsen, Mats Ander, Jim Brouzoulis and Elias Kassa: Simulation of wheel–rail contact and damage in switches & crossings, *Wear,* vol 271, nos 1-2, 2011, pp 472-481

Björn Paulsson, Jay Jaiswal and Anders Ekberg: The EU-project INNOTRACK – a description of highlights and how they have been implemented, *Proceedings 9th World Congress on Railway Research (WCRR 9)*, Lille (France) May 2011, 9 pp (documented on CD). Authors received a Best Paper Award at this congress

Parallel EU projects – Parallella EU-projekt – Parallele EU-Projekte – Projets parallèles avec l´UE

EU11. QCITY

Quiet City Transport

This was an Integrated Project (IP) under the Sixth Framework Programme: Thematic Priority 6 – Sustainable Development, Global Change and Ecosystems. Banverket was a partner (one of 27 from 10 countries) and transferred work in QCITY to CHARMEC and to Professor Jens Nielsen, as reported in project SP10. QCITY ran from 1 February 2005 to 31 January 2009. The co-ordinator of project QCITY was Nils-Åke Nilsson from Acoustic Control ACL AB (now part of Tyréns AB in Stockholm, Sweden). See www.qcity.org.

EU12. RIVAS

RIVAS – Railway Induced Vibration Abatement Solutions

Project leader	Professor Jens Nielsen, Applied Mechanics/ Division of Dynamics
Period	2011-01-01 – 2013-12-31
Budget EU	kEUR 225
Budget CHARMEC	Stage 6: kSEK 300 Stage 7: kSEK 300

For a photo of Jens Nielsen, see page 23

RIVAS is a Collaborative Project within the Seventh Framework Programme under the activity code "Attenuation of ground-borne vibration affecting residents near railway lines". It aims to contribute to technologies for efficient control of the exposure of people to vibration and vibration-induced noise caused by rail traffic. RIVAS focuses on low-frequency vibration from surface lines, which is a concern mainly for freight traffic. However, it can be anticipated that the results will also be applicable to suburban, regional and high-speed operations. Key deliverables include protocols for the evaluation of annoyance and exposure to vibrations, for the assessment and monitoring of the performance of anti-vibration measures, and for the characterization of vibration properties of soils. Mitigation measures for both ballasted track and slab track will be studied. Guidelines will be presented for track and vehicle maintenance, for design of transmission mitigation measures, and for low-vibration vehicles, see www.rivas-project.eu.

The 26 partners (from 9 countries) in RIVAS are Adif (Spain), Alstom (France), Bombardier Transportation (Sweden), BAM (Germany), CSTB (France), CEDEX (Spain), Chalmers/CHARMEC (Sweden), DB (Germany), D2S (Belgium), Eiffage Rail (Germany), KU Leuven (Belgium), Keller (Germany), Lucchini RS (Italy), Pandrol (UK), Rail.One (Germany), RATP (France), Sateba (France), SATIS (NL), SBB (Switzerland), SNCF (France), Trafikverket (Sweden), TÜV Rheinland (Germany), UIC, UNIFE, University of Southampton/ISVR (UK), and VibraTec (France).

The 8 work packages of RIVAS are WP1 Assessment and monitoring procedures (led by DB), WP2 Mitigation measures at source (led by Alstom), WP3 Mitigation measures on track (led by SNCF), WP4 Mitigation measures on transmission/propagation (led by KU Leuven), WP5 Mitigation measures on vehicles (led by Bombardier Transportation), WP6 Dissemination, exploitation and training (led by UIC), WP7 Administrative management (led by TÜV Rheinland), and WP8 Technical co-ordination (led by UIC). Bernd Asmussen, DB/UIC, is co-ordinating the full RIVAS project. It comprises a total of 483 man-months with a budgeted project cost of MEUR 8.3 (including budgeted EU funding of MEUR 5.2) and runs during 36 months starting on 2011-01-01. The commitment of Chalmers/CHARMEC is 20 man-months and relates to WP2, WP3 and WP5. The kick-off meeting for RIVAS was held at UIC in Paris on 2011-02-02. RIVAS Description of Work is dated 2010-11-29. Chalmers is the task leader for WP2.1 Vibration effect of track irregularities and WP5.3 Design of low vibration vehicles.

A training course on the use of their ground vibration software TRAFFIC was hosted by KU Leuven on 27-28 July 2011, with Jens Nielsen attending. CHARMEC's in-house software DIFF for calculating wheel–rail contact forces due to discrete wheel–rail irregularities (such as wheel flats and rail joints) and/or track stiffness irregularities has been integrated with the KU Leuven code TRAFFIC. The Fourier transform of the wheel–rail contact force calculated in DIFF is used as input to TRAFFIC. RIVAS has a test site at Furet/Halmstad (Sweden) where a sheet piled wall is being tested as a mitigation measure to reduce ground vibration. Our work on low-vibration trains in WP5 began with the identification of vehicle parameters influencing the generation of ground vibration (continued work from CHARMEC's project SP18).

Adam Mirza, Jens Nielsen and Philipp Ruest: Train-induced ground vibration – influence of rolling stock: state-of-the-art survey, RIVAS Deliverable D5.1, September 2011, 53 pp

Jens Nielsen, Wouter Beeterens, Bert Stallaert and Eric Berggren: Classification of track conditions with respect to vibration emission, RIVAS Deliverable D2.1, July 2012, 245 pp

Jens Nielsen, Brice Nelain, Roger Müller, Anders Frid and Adam Mirza: Train induced ground vibration – characterisation of vehicle parameters from test data and analysis, RIVAS Deliverable D5.2, August 2012, 65 pp

EU13. D-RAIL

D-RAIL – Development of the Future Rail Freight System to Reduce the Occurrences and Impact of Derailment

Project leader	Docent Anders Ekberg, Applied Mechanics / Division of Dynamics
Co-workers	Professor Roger Lundén, Mr Björn Pålsson, Lic Eng, Docent Elena Kabo, Professor Jens Nielsen and Dr Tore Vernersson, all of Applied Mechanics
Period	2011-10-01 – 2014-09-30
Budget EU	kEUR 250
Budget CHARMEC	Stage 6: kSEK 200 Stage 7: kSEK 400

From the left: Dr Tore Vernersson, Docent Anders Ekberg, Mr Björn Pålsson, Lic Eng, Docent Elena Kabo, Professor Jens Nielsen and Professor Roger Lundén, all of them being active in project EU13. Photo is taken in Chalmersska Huset (the Chalmers House) at Södra Hamngatan 11 in Gothenburg

D-RAIL is a "small or medium-scale focused research project" within the Seventh Framework Programme, with a total budget of MEUR 4.77 of which MEUR 3.00 are the requested EU funding. D-RAIL focuses on freight traffic, identifying root causes of derailment of particular significance to freight vehicles. One key question that will be studied is how independent minor faults (e g, a slight track twist and a failing bearing) could combine to cause a derailment. D-RAIL will extend this study to include expected demands on the rail freight system forecast for 2050. Causes of derailment will be identified and their frequency/impact quantified. The causes will be investigated in detail to further the understanding of mechanisms and conditions under which derailments may occur. In tandem with the above analysis, current monitoring systems and vehicle identification technologies (both wayside and vehicle-mounted) and developing technologies will be assessed with respect to their ability to identify developing faults and potential dangers. Where current systems are shown to be deficient, the requirements for future monitoring systems will be specified. Integration of alarm limits, monitoring systems and vehicles across national borders and network boundaries will be examined and a deployment plan set out based on RAMS and LCC analyses. Procedures for applying speed limits to faulty vehicles, or taking them out of service, will be set out. This will input to standards, regulations and international contracts. Field testing and validation will be made at VUZ's test track in the Czech Republic. The project D-RAIL is jointly co-ordinated by UIC and University of Newcastle and it runs during 36 months starting on 2011-10-01. See www.d-rail-project.eu.

The 20 partners (from 9 countries) in D-RAIL are University of Newcastle (UK), UIC, RSSB (Rail Safety and Standards Board,UK), Technische Universität Wien (Austria), Panteia (NL), Chalmers/CHARMEC (Sweden), Politecnico di Milano (Italy), MMU (Manchester Metropolitan University, UK), Lucchini RS (Italy), Mer Mec (Italy), Faiveley Transport (Italy), Telsys (Germany), Oltis (Czech Republic), VUZ (Czech Republic), DB (Germany), Harsco Rail (UK), SBB (Switzerland), ÖBB (Austria), SNCF (France) and Trafikverket (Sweden).

D-RAIL is divided into 9 work packages: WP1 Derailment impact (led by UIC), WP2 Freight demand and operation (led by University of Newcastle), WP3 Derailment analysis and prevention (led by SNCF), WP4 Inspection and monitoring techniques (led by Mer Mec), WP5 Integration of monitoring techniques (led by DB), WP6 Field testing and evaluation (led by VUZ), WP7 Operational assessment and recommendation (led by DB), WP8 Dissemination & exploitation (led by UIC), and WP9 Project co-ordination (led by UIC and University of Newcastle). CHARMEC works (number of man-months in parentheses) in WP3 (18), WP6 (4), WP7 (2) and WP8 (1). A total of 25 Deliverables are planned with CHARMEC being the lead contractor for three of them.

The D-RAIL Description of Work is dated 11 July 2011. CHARMEC's Anders Ekberg is acting as the scientific and technical co-ordinator for the entire D-RAIL project (the same role he performed in INNOTRACK). Anders Ekberg and Björn Pålsson participated in a joint WP1, WP2 and WP3 meeting in Paris on 18 April 2012. CHARMEC organized the WP3.2/3.3 kick-off in Gothenburg on 3 May 2012, and Anders Ekberg took part in a joint WP3, WP4 and WP5 meeting in Tällberg (Sweden) on 20-21 June 2012. BSc and MSc projects on derailments have been initiated and supervised by us, see below.

Helena Almegius, Jonatan Berg, Alexander Kärkkäinen and Susanna Lindberg: Kan detektorer förebygga urspårning? (Can detectors prevent derailment?; in Swedish but with a detailed abstract in English), BSc Thesis 2012:07, *Chalmers Applied Mechanics,* Gothenburg 2012, 46 pp (and 7 appendices, 1+1+1+1+1+8+1 pp)

Martin Andersson: Derailment in track switches, MSc Thesis 2012:22, *Chalmers Applied Mechanics*, Gothenburg 2012, 40 pp

SP1. LUCCHINI SWEDEN AB (bilateral agreement)

Bilateral agreements have been running since 1987 between Lucchini Sweden (formerly Sura Traction, ABB Sura Traction 1990-96, Adtranz Wheelset 1996-2000) and Chalmers Applied Mechanics (formerly Chalmers Solid Mechanics). CHARMEC's personnel have assisted the Lucchini company and its forerunners on a continuous basis in the design, analysis, testing, documentation and marketing of wheelsets. The main contact now is Erik Kihlberg, who succeeded Lennart Nordhall as President of Lucchini Sweden in April 2009. Contact persons are also Gunnar Eriksson and Peter Jöehrs at Surahammar and personnel at the parent company Lucchini RS in Italy. Several new designs of freight and passenger wheelsets have been developed. In April and June 2012, CHARMEC gave a course for the personnel at Lucchini Sweden on materials, design, maintenance and other aspects of wheelset technology. Roger Lundén also assists Lucchini Sweden on the CEN and ERWA committees, see further page 115.

Parallel special projects – Parallella specialprojekt (SP) – Parallele Sonderprojekte – Projets spéciaux parallèles

SP2. NOISE FROM SWEDISH RAILWAYS

CHARMEC has been involved in Banverket's (now Trafikverket) overall efforts to reduce the noise emitted from Swedish railways since 2002. Results from projects VB4, EU2 and EU3 were utilized in project SP2. Continued work has taken place in project SP10.

Parallel special projects – Parallella specialprojekt (SP) – Parallele Sonderprojekte – Projets spéciaux parallèles

SP3. TRACK FORCE MEASUREMENTS ON X2

An extensive test campaign with field measurements of the track forces caused by Swedish high-speed train X2 was run in October 2002. The cash and in-kind financing (about MSEK 3.0) came from Banverket (now Trafikverket), Lucchini Sweden, SJ AB and CHARMEC.

A bogie was equipped by TrainTech Test Centre (now Interfleet Technology Test Centre) with accelerometers, measuring wheels and a data collection system. The train ran three times Stockholm – Gothenburg (Göteborg) – Stockholm, twice Stockholm – Malmö – Stockholm, and once Stockholm – Sundsvall – Stockholm. The aim was to cover the high-frequency range of the load spectrum (up to around 2000 Hz) where large contributions to peak loads may originate. CHARMEC contributed with a background analysis and calculations.

The results from SP3 have been used in TS8 and other projects. See also CHARMEC's Triennial Report for Stage 3 and under SP11 below.

Parallel special projects – Parallella specialprojekt (SP) – Parallele Sonderprojekte – Projets spéciaux parallèles

SP4 & SP5. VAE AG AND VOESTALPINE SCHIENEN GMBH (bilateral agreements)

For the period 1 January 2002 – 30 June 2003, bilateral agreements were reached between Chalmers/CHARMEC and Austrian switch manufacturer VAE AG (for projects TS7 and MU14) and Austrian rail producer voestalpine Schienen GmbH (for projects MU11 and MU14). From Stage 3, the two Austrian companies joined CHARMEC's Industrial Interests Group under the joint name voestalpine Bahnsysteme GmbH & CoKG.

SP6. DEVELOPMENT OF A QUIET RAIL

Utveckling av en tyst räl

From September 2000, CHARMEC had a development project aimed at the treatment and installation of rails with less noise radiation. Different shielding arrangements and absorbing materials were tested in project SP6. See CHARMEC's Triennial Report for Stage 3 and also project SP10 in the following.

SP7. LATERAL TRACK STABILITY

Lateral spårstabilitet

One of the most feared phenomena in railway operations is the formation of sun-kinks on the track, a phenomenon also known as lateral buckling. Sun-kinks are caused by excessive compressive forces in the rails, owing to high temperature and restrained thermal expansion. Large and rapid lateral deflections of the track occur and may cause derailment of a passing train. The SP7 project was led by Docent Anders Ekberg and Dr (now Docent) Elena Kabo and several co-workers from SP Technical Research Institute of Sweden, see photo.

The resulting axial force in a rail is zero at a certain "neutral temperature". Knowledge of this temperature is important because it governs the maximum temperature that the track can sustain before sun-kinks are likely to occur. In SP7 several existing and proposed methods for measuring the axial force (and thereby the neutral temperature) in an installed rail were studied theoretically, numerically and experimentally.

Experimental setup for the "wave guide method" at the SP laboratory in project SP7. From the left: Docent Anders Ekberg and Dr (now Docent) Elena Kabo of Chalmers Applied Mechanics together with Dr Gunnar Kjell, Dr (now Professor) Erland Johnson, Dr Robert Lillbacka and Mr Lars Jacobsson, Lic Eng, of SP Technical Research Institute of Sweden. Photo taken in 2006

The other focus of project SP7 was on track stability with its dependence on the lateral stiffness of rails, fastenings and sleepers. Non-linear finite element (FE) simulations in 2D and 3D were performed to establish the lateral force-deflection characteristics of a single sleeper embedded in ballast and of a 100 m stretch of the full track. Finally, a "track resonance method" was launched for an experimental study of the overall risk of sun-kinks on an existing track.

Photo: Frida Hedberg, Aftonbladet Bild

Derailment of the last two coaches in a Swedish passenger train on 6 July 1997 between Lästringe and Tystberga on a regional line south of Stockholm and north of Nyköping. The day was calm with few clouds and a maximum temperature of about 25°C. According to eyewitnesses, the lateral buckling and displacement of the track gradually grew as the train braked

SP8. DESIGN OF INSULATED JOINTS

Utformning av isolerskarvar

Project SP8 was led by Dr (now Docent) Elena Kabo. Work in the project WAS shifted to projects TS8, MU18 and EU10, see under these projects.

Parallel special projects – Parallella specialprojekt (SP) – Parallele Sonderprojekte – Projets spéciaux parallèles

SP9. SLEEPER DESIGN FOR 30 TONNE AXLE LOAD

Sliperutformning för 30 tons axellast

The design of new concrete sleepers for the Iron Ore Line (Malmbanan) in Northern Sweden was studied, at the request of Banverket (now Trafikverket), with regard to the increase in maximum axle load from 25 to 30 tonnes. The project was led by Professor Jens Nielsen of Chalmers Applied Mechanics and Dr Rikard Bolmsvik of Abetong (see project MU5). The study ran from July 2004 to June 2005 and was financed by Banverket. See also CHARMEC's Triennial Report for Stage 4 and projects SP12 and SP17 in the following.

Parallel special projects – Parallella specialprojekt (SP) – Parallele Sonderprojekte – Projets spéciaux parallèles

SP10. NOISE REDUCTION MEASURES AND EU PROJECT QCITY

Bullerreducerande åtgärder och EU-projektet QCITY

To comply with noise legislation and support long-term political, environmental and logistical objectives, greater understanding is needed of the emission and propagation of railway noise and the nuisance it causes to people living near railway lines. Several research projects focusing on railway noise have therefore been run at Banverket (now Trafikverket). They include (i) developing technology for frequent and regular measurement of short-wavelength rail irregularities using Banverket's STRIX car, (ii) surveying the market of noise reduction measures, (iii) introducing rail vibration absorbers at hot spots in the railway network, (iv) developing a database of models of tracks and vehicles representative of Swedish conditions to be used with the noise prediction software TWINS, (v) participating in the EU integrated project QCITY (Quiet City Transport) which comprised a total of 1041 man-months and had a budgeted EU funding of MEUR 7.40 (here Banverket was a partner with a commitment of 12 man-months plus in-kind contributions), the aim being to develop an integrated technology infrastructure for the efficient control of road and rail ambient noise, and (vi) participating in the reference group for noise projects under the Green Train Programme in Sweden, see page 117. The aim of project SP10 was to increase efficiency and achieve synergy effects by integrating these projects. This task was assigned to CHARMEC's Jens Nielsen, who worked part-time in the project from January 2005 to November 2009.

A field test with three different types of rail dampers (from Corus Rail, CDM and Schrey & Veit) was performed in September 2008 at the Tjörnarp test site between Höör and Hässleholm on the Southern Main Line with UIC60 rails. In addition, pass-by noise from 14 train passages (8 X60, 2 X40, 1 X12, 2 InterCity and 1 freight train) at a speed of about 70 km/h was recorded at a test track near Kungsängen northwest of Stockholm. Without a noise barrier, the X60 and X40 trains were the quietest trains measured, some 8 dB(A) quieter than the freight train. An installed low barrier was found to be most efficient in reducing TEL (Transit Exposure Level) for the X60 and X12 trains. For detailed results from Tjörnarp and Kungsängen, see CHARMEC's Triennial Report for Stage 5.

SP11. VERTICAL CONTACT FORCES OF HIGH-SPEED TRAINS

Vertikala kontaktkrafter på höghastighetståg

Project leaders	Mr Per Gullers, MSc, Interfleet Technology, and Professor Roger Lundén, Applied Mechanics / Division of Dynamics
Co-workers	Docent Anders Ekberg, Professor Jens Nielsen and Docent Elena Kabo, Applied Mechanics
Period	2005-01-01–2007-12-31 2009-06-01–2010-11-30
Chalmers budget (excluding university basic resources)	Stage 4: KSEK 365 Stage 5: KSEK 435+195 Stage 6: –
Industrial interests in-kind budget	Stage 5: KSEK 730 *(Interfleet Technology)*

Meeting in October 2006 of the reference group for project SP11 at the office of Interfleet Technology in Solna (Sweden). From the left: Per Gullers (Interfleet), Johan Oscarsson (Interfleet), Roger Lundén (CHARMEC), Tohmmy Bustad (Banverket), Lennart Warsén (SJ), Lars Andersson (Interfleet), Jens Nielsen (CHARMEC) and Simon Gripner (Banverket)

During 2000 and 2002, vertical contact force measurements were carried out using an X2 bogie and wheelset, see project SP3. Analysis of part of the measured data revealed that extreme loads have a large high-frequency content, and numerical simulations have indicated that these extreme loads are of vital importance in the degradation of tracks and wheels. The overall aim of project SP11 was to (i) clarify the occurrence of high-frequency vertical wheel–rail contact forces at high-speed operations on Swedish railways, and (ii) further the understanding, prediction and counteracting of cracks in wheels and rails as a consequence of rail and wheel corrugation.

In total, the work contained the following 10 tasks: (1) refinement of a computer-based tool to analyse measured data, (2) state-of-the-art survey of methods for measuring rail corrugation, (3) improvement of filters for force data analysis, (4) DIFF modelling of wheel–rail interaction, (5) FIERCE analysis of rolling contact fatigue (RCF), (6) development of analysis tools for handling of large data files, (7) analysis of rail corrugation data, (8) development of acceptance criteria for rail irregularities, (9) evaluation of rail irregularities in relation to Banverket's (now Trafikverket) database BIS, and (10) writing of reports. CHARMEC was involved in tasks 2, 4, 5, 8 and 10. Project SP11 was conducted through a partnership between Interfleet Technology and CHARMEC. The project was part of the Green Train (Gröna Tåget) Programme in Sweden, see page 117.

Repetitive indentation marks with spacing 3.1 m from a severely damaged wheel

The measurements carried out in the summer of 2007 on the Green Train, at speeds up to 280 km/h have been assessed. In parallel, dynamic vehicle–track interaction at high vehicle speeds has been studied using our computer program DIFF with rotating and non-rotating Regina and X2 wheelsets being implemented (including gyroscopic and centripetal effects), see project TS12.

The influences of wheel structural dynamics and wheel rotation seem to be moderate. It has been suggested that the Interfleet Technology software Track Condition Analyser (TCA, originally trained using X2 measurement data at speeds of up to 200 km/h) could be applied also to vertical contact forces measured at vehicle speeds of up to 280 km/h. However, to cover contributions to the contact forces at 280 km/h due to rail roughness (rail corrugation) in the wavelength interval 3 – 8 cm, the measurements need to be accurate up to 2.6 kHz.

SP11. (cont'd)

It was concluded that the Green Train vehicle design will be fairly sensitive to excitation by sleeper passing and probably also to the excitation by other track irregularities. The reason may be the high unsprung mass and high axle load. On one track section with severe rail corrugation, the calculated 95-percentile of the dynamic component of the vertical contact force increased by 35% when vehicle speed was raised from 200 to 280 km/h. This means that the introduction of future high-speed traffic in Sweden would make it necessary to set requirements for track design, specifying the need to choose resilient rail pads and rails with high bending stiffness, as well as for optimized geometry and material of switches and crossings. In addition, requirements on track maintenance to limit rail surface irregularities and degradation of profiles in crossings and on preserving the conditions of the ballast bed would be needed, see project SP19. See also CHARMEC's Triennial Reports for Stages 4 and 5.

The reference group for project SP11 had members from Interfleet Technology and Trafikverket. For CHARMEC's work in task 5 above, see our MU projects.

Damaged insulated joint at Järna, south of Stockholm. Running direction of train is from left to right. Measurements in project SP11 showed that the wheel of an X2 train travelling at 185 km/h flies over the cavity and then bounces twice with a peak contact force of 350 kN

Per Gullers, Paul Sundvall, Jens Nielsen, Anders Ekberg and Lars Andersson: Track condition analyser – assessment of need for track maintenance based on instrumented wheelset measurements, *Proceedings 16th International Wheelset Congress (IWC16)*, Cape Town (RSA) March 2010, 12 pp (documented on USB)

Peter Torstensson and Jens Nielsen: On the influence of wheel structural dynamics and the effects of wheel rotation on vertical wheel–rail contact force, Research Report 2010:9, *Chalmers Applied Mechanics*, Gothenburg 2010, 17 pp (also listed under project TS11)

Per Gullers, Lars-Ove Jönsson and Jens Nielsen: Vertikala kontaktkrafter vid trafikering med höghastighetståg på banor för blandad trafik – analys av Gröna Tåget-mätningar (Vertical contact forces for high-speed trains running on tracks with mixed traffic – analysis of Green Train measurements; in Swedish), Document TS3247-0000-5-RES, *Interfleet Technology AB*, Solna (Sweden) 2010, 42 pp + 19 supplementary appendices

Per Gullers, Paul Dreik (formerly Paul Sundvall), Jens Nielsen, Anders Ekberg and Lars Andersson: Track condition analyser – identification of rail rolling surface defects, likely to generate fatigue damage in wheels, using instrumented wheelset measurements, *IMechE Journal of Rail and Rapid Transit,* vol 225, no F1, 2011, pp 1-13 (revised congress article). Authors received the 2011 SAGE Best Paper Award

SP12. NEW SLEEPER SPECIFICATIONS

Nya sliperspecifikationer

Project SP12 was initiated by Banverket (now Trafikverket) and based on previous work in project SP9. The design of sleepers for 35-tonne axle load was studied. Although the current maximum axle load on the Iron Ore Line (Malmbanan) in northern Sweden is 30 tonnes, an increase to 35 tonnes may take place in the future. The work was carried out in 2006 and led by Professor Jens Nielsen of CHARMEC and Dr Rikard Bolmsvik of Abetong.

The influence of wheel tread defects (wheel flats) and of non-uniform distribution of support stiffness from the ballast along the sleeper was studied. The bending moments in the sleeper at the rail seats and at the centre were calculated using CHARMEC's simulation model DIFF for dynamic interaction between train and track. The in-situ strain gauge measurements in the track at Harrträsk (close to Gällivare) in September 2006 were also utilized, see project TS9. Sleepers with cracked and non-cracked centre sections were numerically studied, and the risk of fatigue failure was evaluated using statistics gathered through Banverket's (now Trafikverket) wheel damage detector at Harrträsk. The preliminarily proposed dimensioning bending moments in the sleeper for an axle load of 35 tonnes and a maximum train speed of 80 km/h are 22 kNm at the rail seats and -14 kNm at the centre of the sleeper. The corresponding values for today's 25-tonne axle load are 15 kNm and -9 kNm.

SP13. ALARM LIMITS FOR WHEEL DAMAGE

Larmgränser för hjulskador

In Sweden, the criterion for removal of wheels with a flat is based on the length of the flat, which must not exceed 40 mm or 60 mm. In the latter case, immediate action is required. To find a more rational alternative, project SP13 focused on the maximum contact force that a damaged wheel may exert on the rail. In Banverket's (now Trafikverket) existing wayside detectors, the lowest alarm limit had been put at 290 kN.

New alarm limits should consider the risk of rail fracture caused by a damaged wheel. The present study included existing defects in rails, residual stresses induced at welds, and deviations from the neutral temperature of the rail.

Simulations with the in-house computer program DIFF together with Banverket's measurements were used. Results from the field test, with a train containing several intentional and severe wheel defects, which was performed on Svealandsbanan in September 2000, have been re-analysed. In particular, measured peak bending moments in the rail caused by wheel flats have been compared with calculated results using DIFF.

Data from the present project were transferred to the INNOTRACK project EU10 to facilitate international input, synergy and adoption. Project SP13 ran from October 2006 to June 2009 and involved Professor Jens Nielsen, Docent Anders Ekberg and Docent Elena Kabo.

SP14. PARTICLE EMISSIONS AND NOISE FROM RAILWAYS

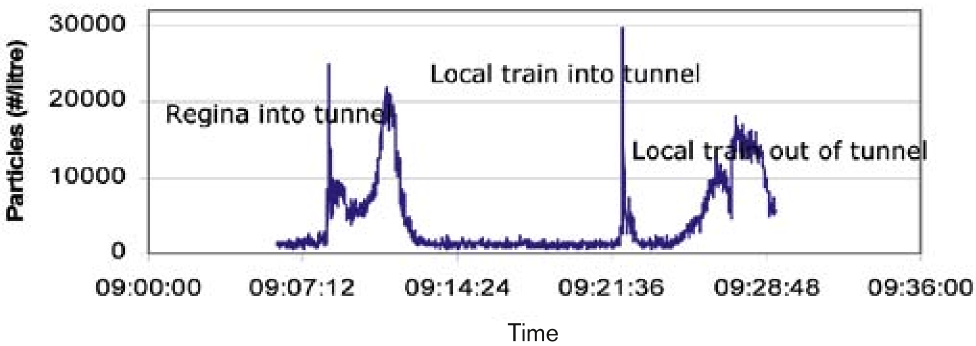
Partikelemissioner och buller från järnväg

Particle emissions will probably be one of the dominating health aspects of railway (and road) traffic in coming years. Mechanisms contributing to the emissions are the continuous wear of wheels and rails (especially on curves), the wear of brake blocks, brake pads and brake discs, and the wear of catenary wires and pantograph contact strips. Parameters of importance for the health effects are the size distribution and chemical composition of the particles. Project SP14 ran from January 2007 to June 2009 and was led by Professor Erik Fridell of IVL Swedish Environmental Research Institute and CHARMEC's Anders Ekberg. The total project budget was KSEK 1525, of which Banverket (now Trafikverket) contributed KSEK 820.

In this project, particle emissions and airflow were registered at the entrance/exit of a single-track tunnel at Hindås, near Gothenburg, for a large number of trains. In addition, onboard measurements of particles and noise were performed on Regina trains travelling between Gothenburg (Göteborg) and Kalmar, and between Gothenburg and Halmstad. The position, speed and acceleration of the trains were monitored by GPS. The tunnel measurements enabled emission factors for PM10 (Particle Matter suspended in air with an aerodynamic diameter of up to 10 micrometre) to be evaluated, see CHARMEC's Triennial Report for Stage 5 and the below diagram.

Erik Fridell, Martin Ferm and Anders Ekberg: Emissions of particulate matters from railways – emission factors and condition monitoring, *Transportation Research Part D: Transport and Environment*, vol 15, no 4, 2010, pp 240–245

Erik Fridell, Anders Björk, Martin Ferm and Anders Ekberg: On-board measurements of particulate matter emissions from a passenger train, *IMechE Journal of Rail and Rapid Transit*, vol 225, no F1, 2011, pp 99-106



Example of result from tunnel measurements at Hindås in project SP14

SP15. COMPUTER PROGRAM FOR DESIGN OF BLOCK BRAKES

Beräkningsprogram för utformning av blockbromsar

In this project, results from the previous project SD4 have been implemented in an industrially adapted computer code for the calculation of wheel and block temperatures. The code can be used to efficiently design tread braking systems for both freight and passenger trains. It can handle stop braking and drag braking, as well as intermediate periods of cooling. This makes it possible to predict the temperature history for a full train route.

The new software has been utilized in commercial projects for Faiveley Transport to calculate temperatures of wheels and brake blocks of future trains in revenue traffic on new lines. Required brake power and train speed, as calculated from data on track gradients, speed limits, axle loads and stipulated brake deceleration, are used as input to the software. The results from the software have also been used to assess the required speed limitations should some components of the total brake system of a train malfunction and other components have to deliver an increased braking effort without being overloaded.

Project SP15 ran from July 2007 to December 2008 and was led by Dr Tore Vernersson and Professor Roger Lundén.

SP16. IDENTIFICATION OF DYNAMIC PROPERTIES IN TRACK OF TIMBER SLEEPERS AND CONCRETE REPLACEMENT SLEEPERS

Identifiering av dynamiska egenskaper i spår hos träsliprar och ersättningssliprar av betong

Project leader	Dr Rikard Bolmsvik, Abetong
Co-workers	Professor Jens Nielsen and Docent Elena Kabo, Applied Mechanics
Period	2009-01-01 – 2009-12-31
Chalmers budget (excluding university basic resources)	Stage 5: KSEK 510 Stage 6: –
Industrial interests in-kind budget	Stage 5: – Stage 6: –

For a photo of Elena Kabo, see page 70

The joint initiative for project SP16 came from Abetong and Banverket (now Trafikverket), and these two parties also shared the financing on an equal basis. As from 2018, new timber sleepers impregnated with creosote will not be allowed by the European Union, and this situation together with the need for replacing single (cracked or rotten) timber sleepers in an existing track formed the background for the project.

Properties of timber sleepers in track were measured, and based on registered data and numerical simulations, a concrete replacement sleeper was designed and tested with a positive outcome. Important issues were preserved vertical stiffness and lateral stability of the track. Master's student Nico Burgelman assisted in the project. Patent is now pending for Abetong's TCS (Tuned Concrete Sleeper).

Nico Burgelman: Concrete sleeper tuned to replace a timber sleeper, MSc Thesis 2009:38, *Chalmers Applied Mechanics,* Gothenburg 2009, 52 pp. Author received Swedtrain's prize for Best Master's Thesis 2009

From the left: Mikael Thuresson of Abetong together with Nico Burgelman, Rikard Bolmsvik and Jens Nielsen at a visit in 2009 to Abetong's sleeper plant at Vislanda (Sweden) in project SP16

SP17. SWITCH SLEEPER SPECIFICATIONS

Växelsliperspecifikationer

Project leader	Dr Rikard Bolmsvik, Abetong
Co-workers	Professor Jens Nielsen, Applied Mechanics, and Dr Elias Kassa, Manchester Metropolitan University (UK)
Period	2009-01-15 – 2010-06-30
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 609 Stage 6: –
Industrial interests in-kind budget	Stage 5: – Stage 6: –

For a photo of Elias Kassa, see page 18

Concrete line sleepers for an axle load of 35 tonnes were studied in project SP12. According to plans, Banverket (now Trafikverket) would introduce specifications for sleepers in switches (turnouts) of a track where a 35-tonne axle load is being foreseen. In particular, the required bending moment capacity of these sleepers should be determined. Project SP17 was financed by Banverket.

Results from measurements at Härad on Svealandsbanan in project TS7 (see CHARMEC's Triennial Report for Stage 4) and from new measurements at Eslöv on the Southern Main Line were utilized together with numerical simulations, using the codes DIFF3D and GENSYS. The work in project SP17 was co-ordinated with that in project EU10.

Rikard Bolmsvik, Jens Nielsen, Per Kron and Björn Pålsson: Switch sleeper specification, Research Report 2010:3, *Chalmers Applied Mechanics,* Gothenburg 2010, 54 pp (also listed under project TS13)

Parallel special projects – Parallella specialprojekt (SP) – Parallele Sonderprojekte – Projets spéciaux parallèles

SP18. GROUND VIBRATIONS FROM RAILWAY TRAFFIC – A PRESTUDY ON THE INFLUENCE OF VEHICLE PARAMETERS

Markvibrationer från järnvägstrafik – en förstudie om inverkan av fordonsparametrar

Project leader	Professor Jens Nielsen, Applied Mechanics / Division of Dynamics
Co-workers	Dr Anders Frid, Ms Siv Leth, Lic Eng, and Mr Adam Mirza, MSc, all three from Bombardier Transportation Sweden, and Dr Martin Li and Mr Alexander Smekal, MSc, both from Banverket (now Trafikverket)
Period	2009-03-01 – 2010-06-30
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 600 Stage 6: –
Industrial interests in-kind budget	Stage 5: kSEK 200 Stage 6: kSEK 200 *(Bombardier Transportation)*

Project SP18 meeting in May 2009 at Bombardier Transportation Sweden in Västerås: Adam Mirza (left) and Jens Nielsen in front of Siv Leth and (from the left) Alexander Smekal and Martin Li from Banverket, Chris Jones from ISVR in Southampton (UK) and Anders Frid

The objective of project SP18 was to identify the most important rolling stock parameters in the process of generating and propagating ground vibrations from railways. Numerical simulations with the code SIMPACK were performed and experimental results from full-scale test runs with a Regina train were utilized. A comprehensive analysis and

SP18. (cont'd)

parametric study was also performed using the code TGV from ISVR (Institute of Sound and Vibration Research) in Southampton, UK.

The present project originated in an EU application denoted ARIV (Abatement of Railway Induced Vibrations) where Chalmers/CHARMEC and Bombardier Transportation Sweden were members of the consortium (consisting of 28 partners from 12 countries and led by Deutsche Bahn). This IP (Integrated Project) application under the Second Call within the Seventh Framework Programme was rejected. A new application under the Third Call was successful, see project EU12.

Adam Mirza, Anders Frid and Jens Nielsen: Markvibrationer från järnvägstrafik – en förstudie med inriktning på inverkan av fordonsparametrar (Ground vibrations from railway traffic – a prestudy aiming at the influence of vehicle parameters; in Swedish), Research Report 2010:8, *Chalmers Applied Mechanics*, Gothenburg 2010, 44 pp

Adam Mirza, Anders Frid, Jens Nielsen and Chris Jones: Ground vibration induced by railway traffic – the influence of vehicle parameters, *Noise and Vibration Mitigation for Rail Transportation Systems, Notes on Numerical Fluid Mechanics and Multidisciplinary Design,* vol 118, Springer 2012, pp 259-266

Adam Mirza, Anders Frid and Jens Nielsen: Ground vibrations from high speed trains on Swedish soil – a first look at the influence of rolling stock parameters, *16th Nordic Seminar on Railway Technology,* Nynäshamn (Sweden) September 2010, 1+23 pp (Summary and PowerPoint presentation. Documented on CD)

SP19. OPTIMUM TRACK STIFFNESS

Optimal spårstyvhet

Project leader	Professor Jens Nielsen, Applied Mechanics / Division of Dynamics
Co-worker	Dr Martin Li, Trafikverket
Period	2009-07-01–2012-06-30 (– 2013-12-31)
Chalmers budget (excluding university basic resources)	Stage 6: kSEK 600 Stage 7: kSEK -

The project is financed by Trafikverket (through CHARMEC's budget)

For a photo of Jens Nielsen and Martin Li, see page 99

The aim of project SP19 is to produce a specification for the selection of a suitable vertical track stiffness (optimum value and/or acceptable range of values) for a nominal track for new and upgraded lines in Sweden. Track stiffness is here defined as the ratio between the magnitude of each of a pair of static vertical (wheel) loads applied onto the two rails and the corresponding elastic rail deflection. In the optimization, wheel–rail contact forces, rolling contact fatigue (RCF), rail vibrations, normal stresses in the rails due to bending, bending moments in sleepers, deformations of fastenings, rail seat loads on sleepers and forces between sleeper and ballast are being considered. RCF in the rail is being calculated according to our FIERCE model.

Based on numerical simulations of the dynamic vehicle–track interaction using the in-house computer program DIFF, the influence of the combined subgrade/ballast bed modulus C_{sb} [(MN/m)/m²] on wheel–rail contact forces and various track responses has been investigated considering stochastic variations of C_{sb}. The calculations were performed for a given vehicle model on a given track superstructure design (rail type 60E1, resilient rail pads with dynamic stiffness 100 kN/mm, A22 concrete monobloc sleepers on ballast). Track irregularities and out-of-round wheels were accounted for by use of an extrapolated ISO 3095 spectrum with wavelengths in the 1/3 octave bands 5–400 cm (corresponding to the frequency range 25–2000 Hz at train speed 350 km/h). The vehicle model was based on the EUROFIMA vehicle with an axle load of 20 tonnes and a maximum speed of 350 km/h.

Significant dynamic contributions to track responses are generated by wheel/rail irregularities. With increasing C_{sb} the dynamic contributions to wheel–rail contact forces, to an RCF index, as well as to rail bending stresses, rail seat loads and sleeper bending moments, are increasing. In addition, high values of C_{sb} lead to high magnitudes of the vertical wheel–rail contact forces at the so-called P2 resonance. A severe excitation of the P2 resonance should be avoided as it could lead to rapid track degradation. These issues set an upper limit for C_{sb}.

For the specified dynamic rail pad stiffness, it was found that the influence of C_{sb} on track vibrations is significant for $C_{sb} < 100$ (MN/m)/m². Above this value, the influence of C_{sb} is moderate, as track stiffness is dominated by the low stiffness of the resilient rail pads. A low C_{sb} may also indicate a potential for severe ground vibrations at the considered high speeds (when vehicle speed is close to or larger than the critical phase velocity of the coupled track-soil system). These issues set a lower limit for C_{sb}.

The influence of C_{sb} on statistical maxima (μ+3σ; mean value plus 3 standard deviations) of different track responses has also been studied. Each track response was normalized with respect to a limit value specified by the corresponding track component manufacturer. For the given wheel/rail irregularity input, it was shown that the RCF index exceeded the indicative limit value. The other track responses did not exceed their limit values. In particular, the use of resilient rail pads leads to low rail seat loads and low sleeper bending moments. Nevertheless, for more severe periodic irregularities or a large discrete wheel/rail irregularity, the maximum track loading will become worse.

The choice of an optimum level of C_{sb} therefore becomes a compromise in order to limit all different track responses. The influence of the standard deviation σ of the C_{sb} variation along the track on each studied type of track response is considerable. To limit track vibration, wheel–rail contact forces, rail bending stresses, rail seat loads and sleeper bending moments, it is concluded that the optimum mean value μ of C_{sb} is in the order of 150 (MN/m)/m^2 and that the standard deviation σ of C_{sb} should be below 30 (MN/m)/m^2. This corresponds to an optimum vertical track stiffness of 90 kN/mm, meaning that two static wheel loads, each of magnitude 90 kN, will give a rail deflection of 1 mm.

In the simulations carried out so far, the track model in DIFF has been taken as linear. In a more general and comprehensive model, the non-linear force-displacement characteristics of rail pad and ballast/subgrade will be accounted for. The influence of different freight and passenger vehicles (axle loads and speeds) will be studied. The commercial code GENSYS will be used to simulate the influence of track stiffness on low-frequency vehicle dynamics. The project plan dated 2009-10-06 has been followed. The work in project SP19 is continuously being discussed with Trafikverket.

Jens Nielsen: Optimum vertical track stiffness – a literature survey, Research Report 2010:1, *Chalmers Applied Mechanics*, Gothenburg 2010, 30 pp

Jens Nielsen: Optimum vertical track stiffness, Research Report 2010:11, *Chalmers Applied Mechanics,* Gothenburg 2010, 63 pp

Parallel special projects – Parallella specialprojekt (SP) – Parallele Sonderprojekte – Projets spéciaux parallèles

SP20. CLASSIFICATION OF WHEEL DAMAGE FORMS

Klassificering av hjulskadeformer

Project leader	Docent Anders Ekberg, Applied Mechanics / Division of Dynamics
Co-worker	Docent Elena Kabo, Applied Mechanics
Period	2010-01-01 – 2011-06-30
Chalmers budget (excluding university basic resources)	Stage 6: KSEK 100
Industrial interests in-kind budget	Stage 6: –

Example of observed damage on freight wheel

In the development of efficient mitigation strategies for wheel damage, it is crucial that underlying causes can be tracked. In this process, a clear and detailed documentation of different observed damage forms is essential. Until now, the documentation process in Sweden has been well established and efficient when it comes to geometry deterioration. However, especially in the case of crack formation, the procedures used have been insufficient and outdated. Project SP20 was launched to improve this situation, and follows a project plan dated 2009-11-19.

A survey of current reporting procedures resulted in a draft proposal that was presented and discussed during a reference group meeting of projects MU18, MU21, MU22 and MU25 on 2010-10-15. Based on the feedback, a revised version was prepared and discussed at a new meeting on 2010-12-18. Additional feedback, mainly regarding the level of detail to employ, resulted in a second revision, which was circulated among the members of a reference group from Bombardier Transportation (Germany and Sweden), Interfleet Technology and Lucchini Sweden, as well as among the members of the CHARMEC Board.

SP20. (cont'd)

The final recommendation for the classification of wheel damage forms has now been issued in both Swedish and English, see below. All but one of the current categories in the widely used wheel damage database FORD have been kept. The new category has been assigned an entirely different code, which means that the old and the new systems can be used in parallel. Thus only minor modifications of the present reporting system are required. However, once these are in place, they will allow the operator/maintainer to switch to the new system whenever this is convenient, and to keep the old system for some vehicles if desired. This allows for a flexible level of detailing in the reporting. As an example, a more detailed reporting (including, e g, extent and severity of damage) can be introduced if requested.

Anders Ekberg and Elena Kabo: Klassifiering av hjulskador (Classification of wheel damage; in Swedish), Research Report 2011:12, *Chalmers Applied Mechanics*, Gothenburg 2011, 7 pp

Anders Ekberg and Elena Kabo: Classification of wheel damage, Research Report 2011:13, *ibidem*, Gothenburg 2011, 7 pp

SP21. OPTIMUM MATERIAL SELECTION FOR SWITCHES

Optimalt materialval för spårväxlar

Project leader	Professor Jens Nielsen, Applied Mechanics / Division of Dynamics, and Professor Magnus Ekh, Applied Mechanics / Division of Material and Computational Mechanics
Co-workers	Docent Elena Kabo, Applied Mechanics, and Mr Dirk Nicklisch, Dipl-Ing, DB Systemtechnik
Period	2010-07-01 – 2012-06-30
Chalmers budget (excluding university basic resources)	Stage 6: kSEK 450

The project is partially financed by Trafikverket and DB (through CHARMEC's budget)

Wear, accumulated plastic deformation and rolling contact fatigue (RCF) are common damage mechanisms in components of switches and crossings (S&C). An innovative methodology for the prediction of these mechanisms for a mixed traffic situation in a switch was developed in the INNOTRACK (EU10) project. It includes: (i) simulation of dynamic vehicle–track interaction considering stochastic variations in input data, (ii) simulation of wheel–rail contacts accounting for non-linear material properties and plasticity, and (iii) simulation of wear and plastic deformation in the rail during the life of the switch component.

The three different materials R350HT, MN13 and B360 have been tested at Chalmers, in the laboratory of the Department of Materials and Manufacturing Technology, for tensile strength at different temperatures and strain rates as well as low-cycle fatigue behaviour. The steels were also investigated metallurgically and metallographically, including hardness measurements and microstructural evaluations. The results from the laboratory measurements have been employed in the calibration of a non-linear material model used in the present predictions of material deterioration.

A specific aim of project SP21 was to apply the simulation methodology to predict rail profile degradation in an existing crossing at Haste in Germany (on the railway line between Hanover and Hamm in Lower Saxony / Niedersachsen). The predicted degradation of the R350HT crossing was compared to field measurements after 5 and 9 weeks of mixed traffic. The initial set of rail profiles had been determined by MiniProf measurements. Stochastic variations in input data (based on two vehicle types, three vehicle speeds, six wheel profiles, and three lateral wheel positions at crossing entry) were considered. Simulations were performed for nine cross sections of a crossing nose with a loading representing mixed traffic at Haste.

The results of the studies have been presented at a meeting with voestalpine and VAE in Austria on 11-12 January 2012 and at an international workshop on S&C in Eslöv (Sweden) on 14-15 February 2012.

Elena Kabo, Magnus Ekh and Jens Nielsen: Prediction of crossing nose profile degradation in a railway turnout, Research Report 2012:6, *Chalmers Applied Mechanics,* Gothenburg 2012, 34 pp (and 2 annexes, 6+6 pp)

Elena Kabo and Anders Johansson: User manual for simulations in the project "Optimum material selection for track switches", Research Report 2012:9, *Chalmers Applied Mechanics,* Gothenburg 2012, 16 pp

SP22. IMPLEMENTING INNOTRACK RESULTS AT TRAFIKVERKET

Implementering av INNOTRACK-resultat vid Trafikverket

Project leader	Docent Anders Ekberg, Applied Mechanics / Division of Dynamics
Co-workers	Professor Per-Olof Larsson-Kråik, LTU, and Docent Elena Kabo, Applied Mechanics
Period	2010-01-01 – 2012-06-30
Chalmers budget (excluding university basic resources)	Stage 6: KSEK 500

The project was partially financed by Trafikverket (through CHARMEC's budget)

The active phase of the EU project INNOTRACK was between September 2006 and December 2009 and the work carried out during that period comprised a total of close to 1300 man-months. The final cost is estimated at approximately MEUR 25 (including a budgeted EU funding of MEUR 10.0), see our project EU10 for more details. INNOTRACK led to a large number of implementable results, and initial analyses have indicated a potential for massive cost savings if these results were to be implemented in operational services. The current project was initiated to aid the implementation of suitable results in Sweden at Trafikverket.

A first priority list for the implementation at Trafikverket has been established and contains the following six items: Insulated joints, Wheel flats and alarm limits, Subsoil stabilization through LC-piling, Switches & crossings, LCC/RAMS, and Grinding. A meeting to discuss further implementations at Trafikverket was held at Chalmers on 16 August 2011 with Annika Renfors and Björn Paulsson from Trafikverket and Roger Lundén and Anders Ekberg from CHARMEC. To co-ordinate activities at the European level, an INNOTRACK Implementation Group has been formed, of which Anders Ekberg is an active member. The current status of the Europe-wide implementation is tracked in a list maintained by this group.

As mentioned under project EU10, a workshop on "Minimum action rules and maintenance limits" was organized by UIC and held at Chalmers on 19-20 October 2010. On 9 December 2010, a seminar arranged by VINNOVA, Trafikverket and Chalmers was held in Stockholm focusing on the benefit of railway research in general and on the involvement of political, administrative and industrial sectors. Trafikverket, UIC and CHARMEC hosted a workshop on switches & crossings in Eslöv (Sweden) on 14-15 February 2012. A three-year field study of rail joint deterioration (carried out in projects MU18 and EU10) has been reported, see below. Conclusions from the study have played an important part in the revision of Trafikverket's regulations for insulated joints. Part of the work on switches & crossings has also been incorporated in Trafikverket's technical regulations.

Wheel flats and alarm limits are further studied in the EC funded project D-RAIL (see EU13) and the UIC funded project HRMS (see SP25). The results will add to the revision of regulations on allowed wheel flats at Trafikverket.

Anders Ekberg and Björn Paulsson (editors): INNOTRACK – Sammanfattning av avslutande teknisk rapport (INNOTRACK – Summary of Concluding Technical Report; in Swedish), *UIC,* Paris 2010, 10 pp

Anton Wahnström: Validation of insulated joints, MSc Thesis 2011:4, *Chalmers Applied Mechanics*, Gothenburg 2011, 34 pp

Johan Sandström, Elena Kabo, Arne Nissen, Fredrik Jansson, Anders Ekberg and Roger Lundén: Deterioration of insulated rail joints – a three-year field study, *Proceedings 9th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM 2012),* Chengdu (China) August 2012, pp 301-308 (also listed under project MU18)

Installation of inclined lime-cement columns under an existing embankment in Sweden. From INNOTRACK Concluding Technical Report

SP23. OPTIMIZED PRESTRESSED CONCRETE SLEEPER

Optimerad förspänd betongsliper

Project leaders	Dr Rikard Bolmsvik, Abetong, and Professor Jens Nielsen, Applied Mechanics / Division of Dynamics
Period	2010-07-01 – 2011-12-31
Chalmers budget (excluding university basic resources)	Stage 6: KSEK 400

The project is funded by UIC

Meeting in July 2011 at Abetong's head office in Växjö. From the left: S K Awasthi, Jens Nielsen, Rikard Bolmsvik, Ajay Singhal, Stefan Svenningsson (Global Sales Director Abetong), Alok Mishra and Ulf Malmqvist (General Manager Abetong Infrastructure)

The objective of project SP23 was to discuss and quantify the different parameters and criteria that are important in the design of concrete monobloc sleepers. The output should serve as a guideline for RDSO (Research Designs and Standards Organisation under the Ministry of Railways) in India in their work to establish a revised sleeper design specification adapted to Indian railway traffic conditions. In a general sense, project SP23 aimed at rationalizing various parameters in the design methodology and manufacturing process to obtain an optimum product with prolonged life and reduced cost. In the project, international sleeper design standards were surveyed and methods for producing sleepers with a consistently high quality and low wear of the production equipment, in combination with improved ergonomic working conditions, were studied. The selection of various production sequences for stressing of wires, compacting of concrete and demoulding etc was discussed.

The project was initiated at a meeting in Växjö (Sweden) on 22 February 2010 followed by a visit to Abetong's sleeper plant in Vislanda. Dynamic vehicle–track interaction was studied using our numerical model DIFF with input data for vehicle and track as specified by RDSO. The influences of rail type, rail pad stiffness, sleeper design and ballast bed stiffness distribution on sleeper bending moments and rail seat loads were investigated in a parametric study. Rail corrugation and wheel flats have been considered.

Rikard Bolmsvik and Jens Nielsen visited the head office of RDSO in Lucknow (Uttar Pradesh, India) on 25-26 November 2010. A study visit to a sleeper factory in Burhwal was also made. The total number of sleeper factories in India is around 80. The factory in Burhwal is one of two using a long-line production method but their long-line method differs in many respects from the long-line system used by Abetong. Some of the differences are the use of steam curing and two to three weeks of water curing. The compacting of the concrete is done by means of vibrating moulds instead of pocket vibrators in combination with a vibrating beam.

A comparison of international sleeper standards showed that there are several similarities but also differences regarding how to determine the sleeper bending moment requirements based on simulation and testing. Theoretical and empirical relations are mixed with assumptions regarding the influence of various vehicle/track parameters on the sleeper performance. For this reason, the current sleeper standards are not tools that can be used for an optimization of prestressed concrete sleepers.

Sleeper optimization without the need for unreasonably conservative safety factors can be performed using a validated model for simulation of the dynamic vehicle–track interaction. The uncertainty (stochastic scatter) in the input values for each vehicle/track parameter needs to be considered. The presence of wheel/track irregularities, such as out-of-roundness, wheel flats, insulation joints and rail corrugation, may generate substantial dynamic contributions to the wheel–rail contact forces, resulting in high rail seat loads and sleeper bending moments.

The support conditions given by the track bed have a significant influence on the generated sleeper bending moments. Hence, regular and controlled maintenance of rolling stock, rails and ballast bed are prerequisites for a successful optimization of the prestressed concrete sleeper. Low rail pad stiffness leads to a reduction of sleeper bending moments. A sleeper design with a narrow central cross-section reduces the sleeper bending moment at the centre.

The existing Indian sleeper design was evaluated in relation to the rail seat bending moment prescribed by the European sleeper standard. It was shown that the capacity of the current Indian sleeper design is well above the bending requirements given in Europe for the same loading case. Recommendations on the production process to meet the demands on quality and durability according to capacity requirements set in the specification and sleeper standard are given in a report delivered to RDSO. Material selection and parameters to obtain good adhesion properties between wires and concrete are discussed and explained.

The proposed guidelines for optimization of design and production of prestressed concrete railway sleepers were presented at a meeting with Ajay Singhal and S K Awasthi of RDSO and Alok Mishra of India Ministry of Railways in Växjö on 25-26 July 2011. A dissemination seminar combined with a sleeper plant visit for UIC members (railway infrastructure administrations) is foreseen in 2012.

Rikard Bolmsvik, Jens Nielsen and A K Singhal: Guideline for design optimization and production of prestressed concrete railway sleepers, Research Report 2011:5, *Chalmers Applied Mechanics,* Gothenburg 2011, 82 pp (and 6 appendices, 3+1+1+32+1+8 pp)

Parallel special projects – Parallella specialprojekt (SP) – Parallele Sonderprojekte – Projets spéciaux parallèles

SP24. DERAILMENT RISKS IN SWITCHES

Urspårningsrisker i växlar

Project leader	Professor Jens Nielsen, Applied Mechanics / Division of Dynamics
Co-worker	Mr Björn Pålsson, Lic Eng
Period	2011-10-01 – 2011-12-31
Chalmers budget (excluding university basic resources)	Stage 6: –
Industrial interests in-kind budget	Stage 6: –

Trafikverket initiated project SP24 and it was to be financed by UIC. Plans and contract were proposed during autumn 2011 with the project divided into three stages: (i) Building of a track switch model, (ii) Simulations of freight trains, and (iii) Simulations of passenger trains. Part of the work in the first stage was carried out during December 2011. The contract with UIC has not been signed and therefore the activities have been terminated. However, part of the work that was planned for SP24 will be carried out in project EU13 (D-RAIL).

Parallel special projects – Parallella specialprojekt (SP) – Parallele Sonderprojekte – Projets spéciaux parallèles

SP25. HARMONIZED MEASUREMENT SITES FOR TRACK FORCES

Standardiserade mätplatser för spårkrafter

Project leader	Docent Anders Ekberg, Applied Mechanics / Division of Dynamics
Co-workers	Docent Elena Kabo and Professor Jens Nielsen, Applied Mechanics
Period	2012-01-01 – 2013-12-31
Chalmers budget (excluding university basic resources)	Stage 6: KSEK 140 Stage 7: KSEK 400
Industrial interests in-kind budget	Stage 6: – Stage 7: –

The project is funded by UIC and Trafikverket

The UIC project HRMS (Harmonization – running behaviour and noise measurement sites) is intended to be a step in the harmonizing of measurement sites in Europe. The objective is to develop a methodology for how to identify safety or commercial risks in the running behaviour of vehicles. The project contains four work packages: WP1 Categorization of sites (will build on the previous UIC project "Axle load checkpoints to categorize measurement sites"), WP2 Limit values (here the focus will be on identifying a framework for establishing limit values of vertical wheel–rail contact forces), WP3 Noise measurements (the reproducibility of noise measurements should be increased), and WP4 Standardized output for data transfer and vehicle identification (in connection to on-going European projects; the focus will be on how to relate measured values to operating vehicles).

ACADEMIC AWARDS

Research in railway mechanics at Chalmers University of Technology has resulted in the conferring of the higher academic degrees (above the Master's level) listed below (up to June 2012).

Licentiate of Engineering (Lic Eng)

Jens Nielsen	1991-02-19
Mikael Fermér	1991-04-09
Åsa Fenander	1994-09-09
Annika Igeland	1994-10-06
Johan Jergéus	1994-11-22
Anders Ekberg	1997-02-18
Tore Vernersson	1997-09-29
Johan Jonsson	1998-05-13
Johan Ahlström	1998-12-11
Lars Jacobsson	1999-01-28
Johan Oscarsson	1999-03-12
Martin Petersson	1999-10-12
Rikard Gustavson	2000-05-11
Clas Andersson	2000-11-17
Torbjörn Ekevid	2000-12-19
Daniel Thuresson	2001-05-16
Carl Fredrik Hartung	2002-11-22
Lars Nordström	2003-01-24
Simon Niederhauser	2003-02-28
Anders Johansson	2003-09-05
Per Heintz	2003-12-03
Göran Johansson	2004-06-03
Per Sjövall	2004-10-01
Anders Karlström	2004-10-21
Elias Kassa	2004-12-16
Eka Lansler	2005-01-12
Anders Bergkvist	2005-06-09
Håkan Lane	2005-06-10
Niklas Köppen	2006-11-10
Johanna Lilja	2006-11-23
Johan Tillberg	2008-06-04
Johan Sandström	2008-10-14
Astrid Pieringer	2008-12-02
Jessica Fagerlund	2009-06-08
Peter Torstensson	2009-11-27
Krste Cvetkovski	2010-04-23
Jim Brouzoulis	2010-05-07
Hamed Ronasi	2010-09-24
Albin Johnsson	2011-02-24
Björn Pålsson	2011-04-14
Martin Schilke	2011-06-08
Sara Caprioli	2011-12-20
Andreas Draganis	2011-12-21
Shahab Teimourimanesh	2012-02-23
Nasim Larijani	2012-05-24

Doctor of Engineering (PhD)

Jens Nielsen	1993-12-16
Mikael Fermér	1993-12-17
Annika Igeland	1997-01-24
Åsa Fenander	1997-05-23
Johan Jergéus	1998-01-30
Anders Ekberg	2000-04-07
Johan Jonsson	2000-06-09
Jonas Ringsberg	2000-09-15
Johan Ahlström	2001-03-02
Johan Oscarsson	2001-04-20
Rikard Gustavson	2002-11-07
Torbjörn Ekevid	2002-12-18
Clas Andersson	2003-06-04
Anders Skyttebol	2004-09-10
Roger Johansson	2005-06-08
Anders Johansson	2005-09-23
Lars Nordström	2005-11-10
Simon Niederhauser	2005-12-09
Tore Vernersson	2006-06-08
Per Heintz	2006-09-28
Göran Johansson	2006-09-29
Daniel Thuresson	2006-10-06
Anders Karlström	2006-10-13
Håkan Lane	2007-05-25
Elias Kassa	2007-10-19
Per Sjövall	2007-11-09
Johan Tillberg	2010-12-10
Astrid Pieringer	2011-05-20
Johan Sandström	2011-11-14
Hamed Ronasi	2012-03-29

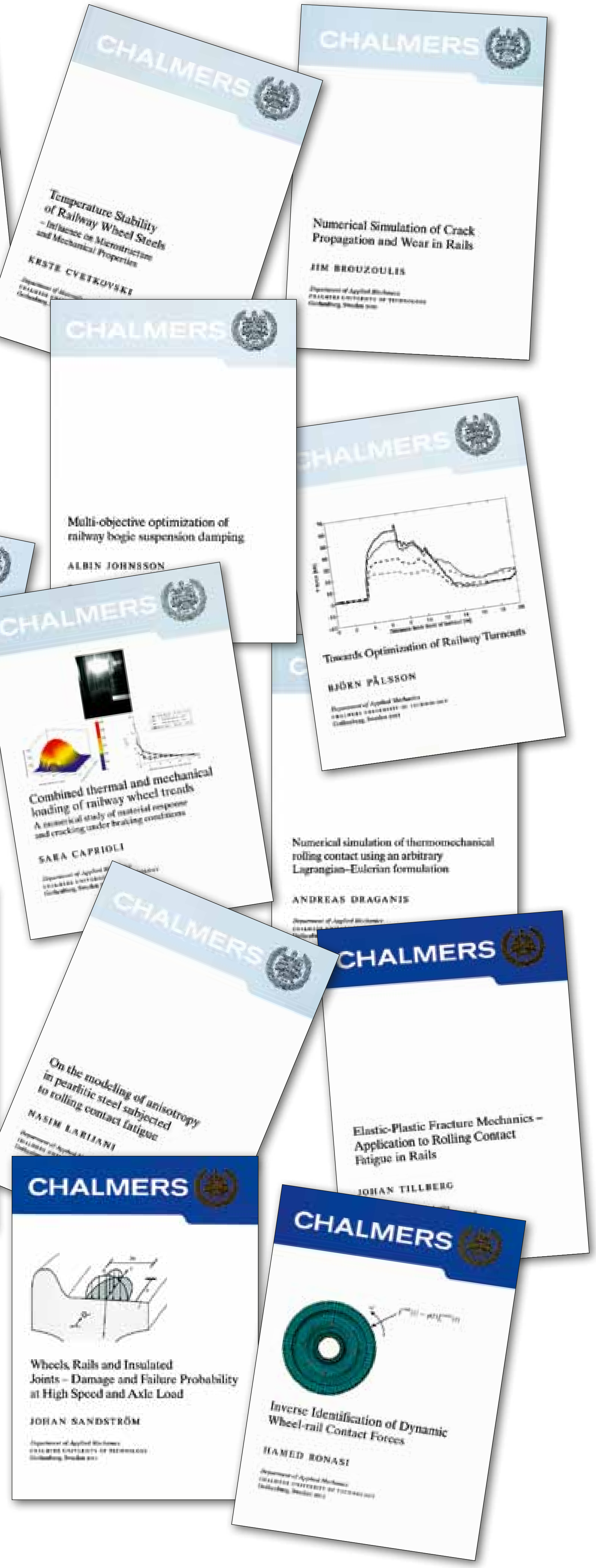
Docent
(highest academic qualification in Sweden)

Roger Lundén	1993-03-23
Jens Nielsen	2000-11-09
Jonas Ringsberg	2004-04-02
Anders Ekberg	2005-08-26
Elena Kabo	2008-12-15
Johan Ahlström	2010-03-08

Adjunct Professor

Jens Nielsen	2006-07-01

Licentiate theses and doctoral dissertations submitted by CHARMEC researchers during Stage 6



INTERNATIONAL CONFERENCES

During Stage 6 (and the months immediately following Stage 6) researchers from CHARMEC have participated in, and contributed to, the following major seminars, workshops, symposia, conferences and congresses:

The 21st IAVSD (International Association for Vehicle System Dynamics) Symposium on Dynamics of Vehicles on Roads and Tracks (IAVSD 2009) in Stockholm (Sweden) 17-21 August 2009

The 10th International Conference on Computational Plasticity (COMPLAS X) in Barcelona (Spain) 2-4 September 2009

The 8th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2009) in Florence (Italy) 15-18 September 2009

The 22nd Nordic Seminar on Computational Mechanics (NSCM-22) in Aalborg (Denmark) 21-23 October 2009

The 16th International Wheelset Congress (IWC16) in Cape Town (RSA) 14-19 March 2010

The 10th French Congress of Acoustics (CFA10) in Lyon (France) 12-16 April 2010

The 4th International Conference on Thermal Process Modeling and Computer Simulation (ICTPMCS 4) in Shanghai (China) 31 May – 2 June 2010

The 10th International Fatigue Congress (IFC10) in Prague (Czech Republic) 6-11 June 2010

The10th International Conference on Recent Advances in Structural Dynamics (RASD 2010) in Southampton (UK) 12-14 July 2010

The 16th Nordic Seminar on Railway Technology in Nynäshamn (Sweden) 14-15 September 2010

The 24th International Conference on Noise and Vibration Engineering (ISMA 2010) in Leuven (Belgium) 20-22 September 2010

The 10th International Workshop on Railway Noise (IWRN10) in Nagahama (Japan) 18-22 October 2010

The 23rd Nordic Seminar on Computational Mechanics (NSCM-23) in Stockholm (Sweden) 21-22 October 2010

The 6th European Conference on Braking (JEF 2010) in Lille (France) 24-25 November 2010

The 9th World Congress on Railway Research (WCRR 9) in Lille (France) 22-26 May 2011

The 2nd International Conference on Computational Modeling of Fracture and Failure of Materials and Structures (CFRAC 2011) in Barcelona (Spain) 6-8 June 2011

The International Heavy Haul Association Specialist Technical Session (IHHA STS 2011) in Calgary (Canada) 19-22 June 2011

The 22nd IAVSD (International Association for Vehicle System Dynamics) Symposium on Dynamics of Vehicles on Roads and Tracks (IAVSD 2011) in Manchester (UK) 14-19 August 2011

The 2nd International Conference on Material Modelling (ICMM-2) in Paris (France) 31 August – 2 September 2011

The International Tribology Conference 2011 (ITC 2011) in Hiroshima (Japan) 30 October – 3 November 2011

The 24th Nordic Seminar on Computational Mechanics (NSCM-24) in Helsinki (Finland) 3-4 November 2011

The 30th International Modal Conference (IMAC XXX) in Jacksonville FL (USA) 30 January – 2 February 2012

The EuroBrake 2012 International Conference in Dresden (Germany) 16-18 April 2012

The 9th International Conference of Contact Mechanics and Wear of Rail/Wheel Systems (CM2012) in Chengdu (China) 27-30 August 2012

The 17th Nordic Seminar in Railway Technology in Tammsvik (Sweden) 3-4 October 2012

The status report that follows applies as of June 2012. The first year of each partner's involvement with CHARMEC is indicated (and before that, by bilateral agreement with the railway mechanics group at Chalmers Solid Mechanics).

Abetong AB (1995 and 1988)

Abetong belongs to the HeidelbergCement Group, and manufactures prefabricated and pretensioned concrete structural components. About 500 people are employed in Sweden where the annual turnover is slightly over MSEK 1 000. Areas of interest for Abetong, whose head office is in Växjö, are the design and manufacture of railway sleepers fitted with fastenings and pads for rails. Of particular interest in the co-operation with CHARMEC are tools for the identification of loads on sleepers installed in tracks, for the structural analysis and design of sleepers for main lines and turnouts, and for prediction of the amount of noise emitted by the sleepers. The main purchasers of sleepers are state railways and railway contractors. Almost half a million Abetong sleepers are produced annually, at wholly or partly-owned and licensed sleeper plants, in 35 different locations in 20 countries around the world.

Banverket/Trafikverket (1995 and 1990)

Trafikverket (the Swedish Transport Administration) is responsible for the construction, operation and maintenance of all state-owned roads and railways in Sweden. Trafikverket is also responsible for producing long-term plans for the transportation systems on roads and railways, at sea and in the air. Trafikverket, whose head office is in Borlänge, has around 6 500 employees. On 1 April 2010, Banverket's duties were taken over by Trafikverket. Areas of interest are the design, construction and maintenance of all types of track structures with focus on high availability and reliability. Of particular interest are the wear and corrugation of the railhead (requiring maintenance grinding) and the overall degradation of the track structure. To understand and predict the effects on the track of proposed higher train speeds and increased axle loads is particularly important. Other important research areas are vibration, noise and safety.

Bombardier Transportation Sweden AB (2000)

Bombardier Transportation is a global manufacturer of equipment for railway operations, and a maintenance and service provider for rolling stock. The company's range of products includes passenger coaches, total transit systems, locomotives, freight cars, propulsion systems, and rail control solutions. The total number of employees is about 36 000, of whom 2 500 work in Sweden. The Swedish office in Västerås is one of the main engineering hubs for the company's Mainline & Metros division. Also located on this site are the global Bombardier Centres of Competence for Acoustics & Vibration, Vehicle Dynamics, and Design for Environment. The company's main area of interest in relation to CHARMEC is the effects of wheel–rail interaction on ride dynamics, wheel wear, wheel damage, and rolling noise. Other areas of interest include the transmission of wheel/rail-generated vibrations into the bogie and car body, the identification of contact forces, and the application of active control systems for enhanced comfort. The company is also looking to increase its understanding of how the requirements for low levels of ground vibrations and external noise can be met.

Faiveley Transport Nordic AB (1997)

Faiveley Transport is one of the world's largest railway equipment suppliers with headquarters in Paris and production units in Sweden, Germany, France, Italy, the United Kingdom and several other countries. The total number of employees is around 5000, of whom 150 are based in Landskrona, Sweden. The main area of interest in the co-operation with CHARMEC is brake systems. The components for tread braking are being investigated, with particular focus on the interaction between brake block and wheel tread. New and better materials for the blocks are sought, with emphasis on the simulation and reduction of wheel and block wear.

Green Cargo AB (2000)

This government-owned Swedish rail logistics company has its head office in Stockholm/Solna and employs about 2 400 people at 20 locations throughout Sweden. Green Cargo operates around 460 locomotives and 7 000 freight wagons, which together covered approximately 25 000 million gross tonne-kilometre in 2011. The Green Cargo network consists of approximately 350 domestic nodes and a number of links to international destinations throughout Europe. Goods are transported by rail freight wherever possible, and rail operations are complemented by road freight to the final destination through co-operation with approximately 200 haulage companies. Areas of interest in the co-operation with CHARMEC include braking performance, noise emission, fatigue strength, and improved designs and materials for wheels and axles.

Interfleet Technology AB (1995 and 1992)

Interfleet Technology is a member of the SNC-Lavalin group, which has approximately 28 000 employees and offices in more than 40 countries. Swedish Interfleet Technology AB is based in Stockholm/Solna, employs 150 people and has a turnover of 166 MSEK (2011). The purpose of the company's involvement with CHARMEC is to market the brand, develop networks, build knowledge, facilitate recruitment, develop existing services and get inspiration for new ventures.

Lucchini Sweden AB (1995 and 1987)

Lucchini Sweden is a railway wheelset manufacturer in Surahammar with 150 years in the business. The company is the only wheelset manufacturer in Scandinavia, and is a wholly-owned subsidiary of Lucchini RS in Italy, one of the major suppliers of wheels and wheelsets for trains in the world. Areas of interest for Lucchini Sweden in the co-operation with CHARMEC are the design, manufacture, mounting, running, braking and maintenance of wheelsets. Of particular interest are new materials for wheels and axles, and noise emission from wheels. The main end users of the wheelsets are passenger and freight train operators in Sweden, Denmark, Finland and Norway. Other major customers include manufacturers of new rolling stock and maintenance providers.

SJ AB (2006)

SJ is a government enterprise which is based in Stockholm. The company's main activities are travel services under its own name, and contract rail services for regional and national transport authorities, almost 100 000 passengers per day in total. The SJ Group has around 4 000 employees, of which on-train staff and train drivers are the largest groups. Investments in 2011 amounted to MSEK 600. Current projects include new high-speed trains, the refurbishment of old passenger coaches and a technical up-grade of the X2 fleet. High traffic safety is a key component of SJ's vision. SJ expects CHARMEC research projects to create an increased understanding of, and a better platform for, improving technical solutions and maintenance services for the rolling stock.

AB Storstockholms Lokaltrafik (2003)

Stockholm Public Transport (SL) has the overall responsibility for public transport in Stockholm County (Stockholms Län) and offers attractive and accessible transport by rail and road. SL is responsible for the operation, maintenance and renewal of rolling stock, and for all fixed railway installations and real estate within the Greater Stockholm Area railway network. The system caters for around 2.7 million passenger trips every day. On an ordinary weekday, approximately 700 000 people use SL's services. Research areas of principal interest to SL are vibrations and noise, track and vehicle maintenance, and materials. Of particular interest are the wear and dynamics of switches (turnouts), and structure-borne noise and material fatigue problems.

SweMaint AB (2006)

SweMaint, whose head office is in Gothenburg, is the leading Scandinavian provider of maintenance services for railway freight wagons. SweMaint has eleven workshops in Sweden and Norway with a total of about 270 employees. The annual turnover is around MSEK 400 and the market share in Sweden is approximately 65%. One of SweMaint's main business areas is the management and operation of a wheelset pool for freight wagons. More than 10 000 wagons with over 30 000 wheelsets are connected to the pool. Areas of interest in the co-operation with CHARMEC are the general improvement of wheelset quality, and the development of cost-effective preventive maintenance programs. Kockums Industrier AB, the Nordic region's only manufacturer of freight wagons, acquired SweMaint in 2007.

voestalpine Bahnsysteme GmbH & CoKG (2003 and 2002)

This Austrian company is one of four divisions of voestalpine AG and has about 11 300 employees worldwide. For the financial year 1 April 2011 – 31 March 2012, the sales of the voestalpine Group (including all four divisions) amounted to MEUR 12 000. voestalpine Metal Engineering Division produces the world's widest range of high-quality rails and switches (turnout systems), wire rod and drawn wire, seamless tubes and semi-finished steel products. The division also offers a complete railway construction service, including planning, transport, logistics, and laying. It also produces its own steel.

voestalpine Schienen GmbH runs Europe's largest and most modern rail rolling mill, in Leoben / Donawitz, Austria. All rails can be produced in supply lengths of up to 120 m with head-special-hardened (HSH®) premium rail quality. The company also owns the rail rolling mill TSTG in Duisburg, Germany.

voestalpine VAE GmbH, with its headquarters in Vienna, Austria, is the world leader in turnout technology for high speed, heavy haul, mixed traffic, light railways and tramways but is also a system provider for the switch area. The VAE group designs and manufactures complete layouts, turnouts and turnout components, such as crossings and switch devices for all kinds of railway track requirements. The main Austrian factory is situated in Zeltweg.

RESULTS AND EFFECTS IN INDUSTRY

In September-October 2012, Trafikverket and our partners in the Industrial Interests Group for Stage 6 expressed the following views.

Abetong

CHARMEC has provided Abetong with an outstanding research environment. Of particular significance for the company is the employment since 2003 of a PhD who trained for five years at CHARMEC, with its invaluable network and expertise in fields that are of major interest to Abetong. In the past, Abetong's role as supplier of precast concrete sleeper technology had only moderate influence on the suppliers of other track components. Armed with greater understanding of the interaction between sleepers and the rest of the track structure, communication with other suppliers has now improved.

Abetong's participation in CHARMEC constantly provides us with better knowledge of the complex interaction between the full track structure and the running train. In the long run, this should lead to an overall optimization of the track structure, using components in harmony rather than a cluster of suboptimized components. Our improved understanding is also valuable when assessing the new ideas presented within the business field of Abetong.

Banverket / Trafikverket

CHARMEC research has helped Banverket (from 1 April 2010, Trafikverket) meet new market demands for higher axle loads and lower noise and vibration levels. The results of this research have had a substantial impact on cost-effectiveness for both Banverket/Trafikverket and its customers.

The development of new projects dealing with track switches (turnouts) has been an important step forward. The co-operation related to the INNOTRACK project of the EU Sixth Framework Programme has been particularly important. Other projects of interest to us have dealt with alarm limits for out-of-round wheels, the improved design of insulating rail joints, safeguarding against rail breaks and track buckling (sun-kinks), and reduced noise emission and ground vibrations.

Several projects have resulted in new specifications and new designs. CHARMEC research has also driven international standardization, which leads to substantial cost savings.

The Principal Agreement for Stage 7 means that CHARMEC will support Trafikverket with competence in research, technical competitive edge resources, implementation of research results, and identification of future research areas and projects. This new role is unique and will give Trafikverket new possibilities.

Bombardier Transportation Sweden

CHARMEC's wheelset research projects dealing with rolling contact fatigue, damage and cracks have been essential for our understanding of the behaviour of wheels in revenue traffic. The company initiated a CHARMEC project on wheels and rails for train speeds of 250 km/h under Swedish conditions, with mixed traffic and a harsh climate. CHARMEC's work with railway noise is also important for the development of quieter trains.

Our ambition to improve the vibrational and acoustic behaviour of trains is reflected in the fact that Bombardier has initiated new CHARMEC projects in this area. Bombardier's involvement in the project looking at multi-objective optimization of vehicle dynamics properties and active technology fits in with the company's objective to find even better and more cost-efficient solutions for vehicle dynamics design. We believe that the results will lead to the development of new systems and components for bogies and car bodies.

Faiveley Transport Nordic

The on-going renewal of block braking systems is driven by the need for higher train speeds, increased axle loads and lower noise levels. Faiveley Transport is continuously developing new block braking solutions for the world market. A broad approach, which combines theoretical models and results from rig and field tests, has been developed together with CHARMEC. The block braking of freight and passenger wagons should be optimized with regard to high braking power in combination with low wear on blocks and wheels, and low noise levels from the wheels. The CHARMEC projects address the extremely high level of safety and reliability that is required for these systems.

Green Cargo

The co-operation with CHARMEC has been very important in several cases relating to fatigue analysis and prediction. CHARMEC personnel supplied Green Cargo with the necessary crack propagation calculations to develop an, from a safety perspective, appropriate maintenance schedule for wheel axles of a certain type. CHARMEC has also investigated critical loads on locomotive wheels to understand why cracks are developing in a certain wheel type. This analysis is critical if Green Cargo is to be able to develop appropriate remedies to overcome this problem. Furthermore, CHARMEC has continued to support the development of composite brake blocks, a very important initiative for decreasing freight transport noise.

Interfleet Technology

CHARMEC has given Interfleet Technology an outstanding research environment. We have gained a better understanding of wheel–rail contact forces, material properties, crack initiation, crack propagation, fatigue failure, maintenance, brake systems etc, all of which have benefitted the company's clients. Interfleet Technology has employed a PhD from CHARMEC, and sees a potential for recruiting more PhDs from CHARMEC. Interfleet appreciates the valuable contact network that CHARMEC brings.

Lucchini Sweden

A significant achievement in the co-operation with CHARMEC in recent years has been the development of new freight wagon wheelsets for 25 and 30 tonne axle loads suitable for a Nordic climate. These wheelsets must fulfil stringent requirements to comply with various national and international standards. The brake test rig on the company's premises in Surahammar, originally developed in collaboration with Chalmers, has been extremely important in this work.

Optimized geometries of wheels and axles for new applications have recently been developed, some of which will be submitted for approval according to Technical Specifications for Interoperability (TSI). CHARMEC personnel have assisted Lucchini with technical developments and design calculations, improved workshop practices, documentation and marketing of our products, technical meetings with customers, and have represented Lucchini Sweden on the CEN and ERWA committees.

SJ

CHARMEC has provided support and expertise to SJ in several projects. Recent examples are the reviewing, evaluation and mapping of critical dimensional parameters of existing old wheelsets still in use. In addition, the braking performance of old wheels with brake block systems has been compared with the performance of wheels with a newer design. CHARMEC is highly appreciated and plays an important role in the bringing together of people from the industry, operators, infrastructure and universities.

In relation to particle emissions, which is an important environmental issue for the company today, SJ has benefitted from research results provided by CHARMEC. SJ has also consulted with CHARMEC when assessing technical reports. During Stage 7, SJ plans to increase its participation in CHARMEC projects and reference groups.

Storstockholms Lokaltrafik (SL)

SL claims that scientifically structured research at a high international level is crucial to the railway industry when maintaining and developing infrastructure and rolling stock. Theoretical models must be combined with laboratory and in-field tests.

CHARMEC's research results have given SL more confidence when planning wheel and track maintenance, and preventing noise from the vehicle/track system. CHARMEC's participation in international research projects and international conferences has also helped SL succeed in its endeavours. CHARMEC membership has given SL an important network of contacts and expertise.

SweMaint

CHARMEC has provided SweMaint, and its owner Kockums Industrier AB, with an information hub and research environment – and a speaking partner for technical issues of importance to the company. The MU projects have been particulary interesting because they relate to wheelset performance.

CHARMEC has assisted with studies on how to improve the reliability of wheels and axles, and by discussing technical improvements. For the future we look forward to increasing our understanding of strategic maintenance programmes, both in relation to the wheelset and to the wagon itself, with a view to optimize the economic performance of the complete vehicle.

voestalpine Bahnsysteme

Understanding the mechanisms of crack initiation and crack growth in rails caused by wheel–rail contact is vital for voestalpine Schienen. During Stages 5 and 6, the co-operation with CHARMEC has focused on simulation models for the early growth of small cracks, the prediction of crack propagation directions and wear. These studies will continue in Stage 7.

For VAE, the co-operation with CHARMEC has led to a better theoretical understanding of forces, stresses, and wear inside a turnout. Different crossing nose materials were tested during Stages 5 and 6. A multi-body system model of a complete turnout and a finite element model of the crossing nose were also developed. These models will be used to analyse material behaviour in crossings and predict life expectancy.

SPECIAL EVENTS AND ACHIEVEMENTS

Some of the events and achievements during Stage 6 that have not been reported elsewhere are presented here.

Board meetings relocated

Six of the twelve meetings of the CHARMEC Board during Stage 6 were combined with visits to organizations outside Chalmers: to Bombardier Transportation Sweden AB in Västerås on 26 November 2009; to SJ AB in Stockholm on 10 June 2010; to the Royal Institute of Technology (KTH) in Stockholm on 2 December 2010; to Kungliga Ingenjörsvetenskapsakademien, IVA (the Royal Swedish Academy of Engineering Sciences) in Stockholm on 10 May 2011; to Lucchini Sweden AB in Surahammar on 29 November 2011, and to Sweco AB in Stockholm on 2 May 2012.

VINNOVA

The NUTEK/VINNOVA basic funding of CHARMEC (total of kSEK 52 300) ceased during Stage 4. Separate applications to VINNOVA from research groups at CHARMEC have later been granted, see projects TS11, VB10, MU18, EU10, and AP4. During 2011-2012, an evaluation of the impact of the NUTEK/VINNOVA Competence Centres is being carried out by VINNOVA.

VR

An application from CHARMEC researchers to Vetenskapsrådet (VR; the Swedish Research Council) was approved, see project MU25. VR is a "government agency that provides funding for basic research of the highest scientific quality".

Family Ekman's Research Donation

Means from this donation to Chalmers University have financed projects SD6 and SD9.

Banverket / Trafikverket in CHARMEC

As part of Banverket's sectoral responsibility for the Swedish railways, this government agency appropriated a basic contribution for CHARMEC's research and for the centre's training and examination of PhDs in railway mechanics during Stage 6. As of 1 April 2010, Banverket is a part of the new and larger agency Trafikverket (the Swedish Transport Administration), which is responsible for all modes of traffic: on roads and railways, at sea and in the air. Trafikverket builds, maintains and operates all national railways.

Areas of Advance

Chalmers University of Technology has profiled its research activities around eight so-called Areas of Advance (in Swedish: Styrkeområden). Two of these areas that relate to CHARMEC are Materials Science where CHARMEC provides applications that in many aspects are extreme, and Transport where railway mechanics issues are key to a competitive railway transport system. We have participated in seminars arranged by the two areas. Further, researchers at CHARMEC have received financial support from the area Transport during Stage 6.

KTH

Roger Lundén continues to serve on the Advisory Board for SAMBA projects at KTH Railway Group. Several of CHARMEC's doctoral students have taken general courses in railway technology at KTH (the Royal Institute of Technology in Stockholm). Collaboration also takes place between research groups at KTH and Chalmers, for example in projects MU20 and MU22. Professor Mats Berg of KTH Railway Technology served on the Board of CHARMEC during Stage 6.

LTU

Collaboration with Luleå JVTC (the Railway Research Center at Luleå University of Technology in northern Sweden) takes place in project TS15 and others.

RTRI

A contract between CHARMEC and the Railway Technical Research Institute (RTRI) in Tokyo (Japan), focusing on "Fatigue and damage of rails", has been agreed and involves an exchange of researchers. Dr Motohide Matsui from RTRI arrived at Chalmers in February 2012 and will stay for about one year. He will then be succeeded by a new researcher from RTRI.

After the conference IWRN10 in Nagahama (Japan) in October 2010, CHARMEC's Thomas Abrahamsson, Jens Nielsen, Astrid Pieringer and Peter Torstensson visited RTRI. A visit to RTRI was also made after the conference CM2012 in Chengdu (China) in August 2012, by Roger Lundén, Shahab Teimourimanesh and Tore Vernersson.

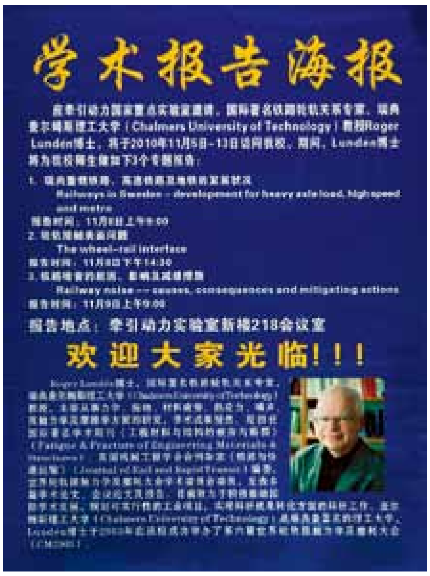
Dr Motohide Matsui of RTRI in his office at CHARMEC

ViF

An agreement has been reached in May 2012 between Chalmers/CHARMEC and Kompetenzzentrum Das virtuelle Fahrzeug Forschungsgesellschaft mbH (ViF) in Graz (Austria). ViF is a so-called K2 Centre in the COMET programme for excellent technologies under the Austrian federal government.

Southwest Jiaotong University

Following an invitation by Professor Weihua Zhang, Roger Lundén visited the State Key Traction Power Laboratory (TPL) at this university in Chengdu (China) on 8-12 November 2010 and delivered three lectures titled "Railways in Sweden – development for heavy axle load, high speed and metro", "The wheel-rail interface", and "Railway noise – causes, consequences and mitigating actions". The ongoing construction of high-speed railways in China was discussed.



Poster for the three Chengdu lectures

Semi-annual reports

Every six months, as of 31 December and 30 June, all CHARMEC leaders of current projects prepare a two-page report on the progress of their projects during the preceding six months. The headline topics specified by the Board in each case are: Background and aims, Reference group, Work performed, Results achieved, Published material, Future plans, Check against initial schedule, Follow-up of budget, and Miscellaneous. All of these two-page reports are edited, compiled into a document (about 50 pages) and submitted to the CHARMEC Board before their next meeting when they are studied and discussed. All semi-annual reports have been written in English since 30 June 2003.

Project reference groups

Most of CHARMEC's projects have had a Project Reference Group (PRG) since Stage 3. A PRG should be a forum for the informal presentation and discussion of research results and for planning future activities (within the framework decided by the Board for the overall project plan). The mutual transfer of knowledge between researchers and industry (including Banverket/Trafikverket) should be furthered, and the implementation in industry promoted. Doctoral students should be encouraged by the PRG to make study visits and learn about the activities of the centre's partners. Employees of these partners should be encouraged to spend time working at Chalmers. A PRG meets once or twice a year, and the project leader is the convener. Some projects have a joint PRG.

At its meetings on 30 May and 24 September 2008, the Board decided that all doctoral projects should have a PRG, that notes should be taken at all meetings, that these notes should be sent to CHARMEC's Director and archived, and that the dates of the PRG meetings should be listed in the semi-annual reports. The previous Directives for PRGs dated 2001-05-28 were replaced by new ones dated 2008-09-24.

Appointment of Docent

After an expert review of his academic achievements and a "docent lecture", Dr Johan Ahlström was awarded the degree of Docent on 8 March 2010. The reviewing experts were Professor Jens Bergström of Karlstad University (Sweden) and Professor Sten Johansson of the Institute of Technology at Linköping University (Sweden). The title of Johan Ahlström's lecture was "Engineering metals for demanding applications – how to evaluate their performance?". Johan Ahlström earned his doctorate at Chalmers in 2001 when working in the CHARMEC project MU2.

Publishing and other awards

The Master's student Nico Burgelman in project SP16 received Swedtrain's prize for Best Master's Thesis 2009. For their article in IMechE Journal of Rail and Rapid Transit, vol 224, no F4, 2010, see project EU10, Dirk Nicklisch, Elias Kassa, Jens Nielsen, Magnus Ekh and Simon Iwnicki obtained the 2010 SAGE Best Paper Award and the IMechE Railway Division Prize – T A Stewart-Dyer / F H Trevithic Prize. The latter prize was also awarded to Andrea Gianni, Andrea Ghidini, Tord Karlsson and Anders Ekberg for their article in the same journal, vol 223, no F2, 2010, see the Triennial Report for Stage 5.

At the 22nd IAVSD Symposium in Manchester (UK) on 27-30 August 2011, the paper presented by Björn Pålsson, see project TS13, received the Taylor & Francis Best Oral Paper Award. For their contribution at the WCRR in Lille (France) on 22-26 May 2011, see project EU10, Björn Paulsson, Jay Jaiswal and Anders Ekberg received a Best Paper Award. The article in IMechE Journal of Rail and Rapid Transit, vol 225, no F1, 2011, see project SP11, by Per Gullers, Paul Dreik, Jens Nielsen, Anders Ekberg and Lars Andersson was appointed the winner of the 2011 SAGE Best Paper Award by the Editor and Editorial Board.

Doctoral examinations

CHARMEC's four doctoral examinations during Stage 6 are listed on page 106. Based on their work during the same period, the following students will defend their doctoral dissertations during the autumn of 2012: Jim Brouzoulis in project MU20 on 5 October, Krste Cvetkovski in project MU23 on 16 October, and Peter Torstensson in project TS11 on 2 November.

Björn Paulsson doctor honoris causa

CHARMEC's former chairman Björn Paulsson, see page 8, has been awarded an honorary doctorate at Luleå Technical University, LTU. The degree was conferred at a graduation ceremony on 13 November 2010.

Exchange with voestalpine Bahnsysteme

voestalpine

As previously, meetings between CHARMEC researchers and their Austrian colleagues at rail manufacturer voestalpine Schienen in Leoben and switch manufacturer VAE in Zeltweg have been held twice a year during Stage 6. Experts have also been invited to these two-day meetings from the Austrian Academy of Sciences (Erich Schmidt Institute of Materials Science) and the Materials Centre Leoben, which are both related to the University of Leoben. More recently, people from the Competence Centre Virtuelles Fahrzeug (ViF) in Graz have also taken part. The dates and venues during Stage 6 were 14-15 January 2010 in Leoben and Zeltweg, 31 May – 1 June 2010 in Gothenburg, 19-20 January 2011 in Leoben and Zeltweg, 26-27 May 2011 in Gothenburg, 11-12 January 2012 in Leoben and Zeltweg, and 30-31 May 2012 in Gothenburg. At the last meeting, 29 people participated. The next meeting will be held in Austria on 14-15 January 2013.

Abetong's licensees

ABETONG HEIDELBERGCEMENT Group

CHARMEC's Anders Ekberg and Jens Nielsen contributed to Abetong's licensee meeting in Ystad (Sweden) on 1-3 June 2010 where 35 people participated. The licensees came from Africa, Asia, Australia and Europe.

Sleeper factory of Abetong's licensee MABA Fertigteilindustrie GmbH in Sollenau, Austria

LKAB and Heavy Haul

The mining company LKAB in Kiruna (Sweden) has observed wheel damage on its trains (axle load 30 tonnes) running on Malmbanan (Iron Ore Line in northern Sweden and Norway) and has engaged researchers from CHARMEC in a broad investigation to clarify the reasons behind the damage and, if possible, to find countermeasures. This work is ongoing and follows a project plan dated 2011-09-06. CHARMEC also assists LKAB and its subsidiary MTAB by solving problems with braking performance on their new iron ore wagons and locomotives.

CHARMEC is a member of the local organization Nordic Heavy Haul (NHH), which is in turn a member of the International Heavy Haul Association (IHHA).

On the initiative of by CHARMEC, 20 reviewed papers from the IHHA conference 2009 in Shanghai (China) were published in a Special Issue of IMechE Journal of Rail and Public Transit (vol 224, no F5, September 2010) on Heavy Haul and Innovative Development with a Guest Editorial written by Chris Barkan, Robert Fröhling, Roger Lundén, Klaus Riessberger and Michael Roney. Three of the 20 papers came from CHARMEC.

Editorial Board of JRRT

Since 2005, Professor Simon Iwnicki from Manchester Metropolitan University (MMU) in the UK has been the Editor-in-Chief of the IMechE Journal of Rail and Rapid Transit (JRRT) and CHARMEC's Roger Lundén has been a member of its Editorial Board. Several research results in railway mechanics from Chalmers/CHARMEC have been published or accepted for publication in JRRT (around 45 articles up to September 2012). IMechE stands for the Institution of Mechanical Engineers. Roger Lundén attended an Editorial Board meeting at the IMechE premises on Birdcage Walk in Westminster in London (UK) on 9 May 2012 and has earlier taken part in telephone meetings.

Editorial Board of FFEMS

Since 2004, Roger Lundén has been a member of the Editorial Board of the international scientific journal Fatigue & Fracture of Engineering Materials & Structures (FFEMS). Several articles by CHARMEC's researchers have been published in FFEMS.

Contact mechanics course

A graduate course on contact mechanics was given at Chalmers by Professor Roger Lundén and Professor Magnus Ekh during January to March 2010. Eight of CHARMEC's doctoral students attended. The two parts of the course were "Engineering contact mechanics" (Lundén) and "Computational contact mechanics" (Ekh).

Nordic Track Technology Engineering Training

This is a one-week course with the Swedish title Nordisk Banteknisk Ingenjörs-Utbildning (NBIU) which is held annually for about 30 participants from Denmark, Finland, Norway and Sweden. CHARMEC's Jens Nielsen contributes with the lecture "An introduction to train-track dynamics".

Vocational training railway projects

At Campus Varberg, some 90 km south of Gothenburg, a two-year training programme is being delivered for students aiming for a vocational career as engineers working with projecting in the railway sector. The programme was initiated by Banverket (now Trafikverket), lies under the Swedish National Agency for Higher Vocational Education and is organized by Folkuniversitetet. Roger Lundén serves on the advisory board which has met eleven times since autumn 2009.

Swedish Mechanics Days

A two-day conference titled "Svenska Mekanikdagar" (Swedish Mechanics Days) is held every other year and normally circulates between Swedish universities and institutes of technology. The latest conference was arranged by Chalmers Applied Mechanics in Gothenburg on 13-15 June 2011. Several of CHARMEC's researchers have presented their results at the conferences but these minor papers are not included in the reference lists of the CHARMEC projects in the foregoing.

ERWA and IWC

Ten wheelset manufacturers from eight European countries, including Lucchini Sweden, belong to the European Railway Wheels Association (ERWA). This association was launched in Rome (Italy) in 2001 and is since 2004 known as the UNIFE Railway Wheels Committee. UNIFE (Union des Industries Ferroviaires Européennes) is the Union of European Railway Industries.

The aim of ERWA is to contribute to "improvements in wheels and wheelsets by focusing on safety, reliability and economic efficiency". The association's activities include "the definition, adaptation and implementation of advanced technology". During Stage 6, Roger Lundén continued to serve on ERWA's Technical Committee and took part in several meetings, most of which were held at UNIFE in Brussels (Belgium). The 10th Annual Meeting of ERWA on 17-19 May 2010 was hosted by Lucchini RS in Taormina (Italy) and the 11th meeting on 30-31 May 2011 by CAF in Seville (Spain). The 12th Annual Meeting in Dortmund (Germany) on 14-16 May 2012 was hosted by Bochumer Verein.

ERWA has assumed overall responsibility for the International Wheelset Congresses (IWC). At the 16th IWC in Cape Town (RSA) on 14-19 March 2010, four researchers from CHARMEC participated. Roger Lundén served on the technical committee for the congress.

Lucchini RS

A CHARMEC group, see photo, visited the Lucchini RS plant at Lovere in Lombardy (Italy) on 21 January 2011, guided by the plant´s Andrea Ghidini and Lucchini Sweden's Erik Kihlberg. The plant was founded in 1856 and presently has about 2000 employees. Special interest was paid to the steel mill, the forge shop for axles and wheels, the machining shop and the laboratories. Lucchini RS now has subsidiaries in China, Poland, Sweden and the UK. Lucchini RS delivers the axles and wheels which are machined and assembled by Lucchini Sweden in Surahammar.

CHARMEC group visiting Lucchini RS.
From the left: Krste Cvetkovski, Erik Kihlberg, Sara Caprioli, Elena Kabo, Tore Vernersson and Shahab Teimourimanesh

Swedtrain

People from CHARMEC take part in the meetings of Swedtrain, the Swedish Society of Railway Industries, and we hosted the meeting on 14 April 2010. The present chairman of Swedtrain is Klas Wåhlberg, CEO of Bombardier Transportation Sweden. Magnus Davidsson is Swedtrain's project leader. Our Anders Ekberg takes part in the Research and Development group of Swedtrain, which has members from Bombardier Transportation, CHARMEC, Interfleet Technology, KTH Railway Group and JVTC at Luleå Technical University.

VTI

People from CHARMEC have taken part in the annual meetings arranged by VTI (The Swedish National Road and Transport Research Institute). At the meeting in Linköping (Sweden) on 11-12 January 2012, Anders Ekberg's lecture had the title "Hur vinterförhållanden påverkar den mekaniska nedbrytningen av järnvägen" (How winter conditions influence the mechanical degradation of the railway; in Swedish).

Part of stand at Nordic Rail in October 2011. CHARMEC's Jens Nielsen (right) and VTI's Tarja Magnusson (left) serve the visitor in the middle

Nordic Rail Fair

CHARMEC took part in the 8th and 9th Nordic Rail trade fairs at the Elmia Exhibition Centre in Jönköping (Sweden) on 6-8 October 2009 and 4-6 October 2011, respectively. We shared a stand with KTH Railway Group, Luleå Railway Research Center (JVTC) and the Swedish National Road and Transport Research Institute (VTI). Our research projects were displayed on wall plates and printed material was distributed. CHARMEC's Anders Ekberg, Kalle Karttunen, Roger Lundén, Jens Nielsen and Sadegh Rahrovani served at the latest fair. The stand was sponsored by VINNOVA.

16th Nordic seminar on railway technology

The seminar was arranged by Trafikverket on 14-15 September 2010 in Nynäshamn, some 60 km south of Stockholm, with about 150 participants. 12 persons from CHARMEC took part and contributed with 13 presentations. These are listed under the project descriptions in the previous section.

CM2012

The International Conference on Contact Mechanics and Wear of Rail/Wheel Systems, held every third year, is central to CHARMEC's activities. At CM2012 in Chengdu (China) on 27-30 August 2012 our researchers presented 14 contributions. The Key Note Lecture delivered by Anders Ekberg is listed under project MU22.

Road Shows

Before the new Principal Agreement, which applies from 1 July 2012, was drawn up, CHARMEC staged a series of so-called Road Shows where some of our project leaders and researchers visited Trafikverket and the individual members (as well as two prospective members) of the Industrial Interests Group, see list on page 12. CHARMEC's resources were presented and possible future projects of mutual interest were discussed.

Chicago Workshop

The Federal Rail Administration (FRA) together with the Association of American Railroads (AAR) arranged a workshop in Chicago (USA) on 26-27 July 2011. Rolling contact fatigue was discussed for the expected future mix of high-speed passenger trains (> 200 km/h) and heavy freight trains (axle load > 30 tonnes) on US railroads. Seven international experts were invited to the workshop, among them Anders Ekberg from CHARMEC and Richard Stock from voestalpine.

IWRN 11

CHARMEC will arrange the 11th International Workshop on Railway Noise (IWRN 11) on 9-13 September 2013 at Bohusgården. This is a hotel and conference centre located in the city of Uddevalla on the west coast of Sweden, approximately 90 km north of Gothenburg.

The members of the local organizing committee are CHARMEC's Jens Nielsen (chair), Roger Lundén, Wolfgang Kropp and Astrid Pieringer, together with Anders Frid of Bombardier Transportation Sweden. Jens Nielsen is now also the chairman of the international committee for the IWRN conferences.

For more information see www.chalmers.se/iwrn11.

Green Train Programme

CHARMEC has made minor contributions to the development project Green Train (Gröna Tåget), run by Banverket/Trafikverket, Bombardier Transportation Sweden and KTH Railway Group during the years 2005-2011. This train "for tomorrow's travellers" is meant to be used on existing tracks but also, at 300 km/h or more, on future dedicated high-speed lines in Sweden. It features low energy consumption and track-friendly gear and suspension, and is designed to function in a Nordic winter climate. Roger Lundén took part in the project's final seminar at KTH on 25-26 January 2012.

TSI

Interfleet Technology, Kockums Industrier and Lucchini Sweden have taken part in TSI approval of wheelsets assisted by CHARMEC. The Lucchini/CHARMEC brake test rig in Surahammar was used. The acronym TSI stands for Technical Specifications for Interoperability, which are issued by the European Commission.

EU projects

The seventh Framework Programme (FP7) runs for the period 2007-2013. During Stage 6, CHARMEC has finalized its work within the INNOTRACK project and began its work in the new projects RIVAS and D-RAIL. All three projects belong to FP7, see projects EU10, EU12 and EU13 in the previous section. CHARMEC's Anders Ekberg served as the technical and scientific co-ordinator for the entire INNOTRACK project at European level and has assumed the same role for D-RAIL. The former chairman of the CHARMEC Board, Björn Paulsson, served as INNOTRACK's project manager, based at UIC in Paris.

INNOTRACK Concluding Technical Report

This report (286 pages) was compiled for the International Union of Railways (UIC) by Anders Ekberg and Björn Paulsson with layout and production performed by Renée Stencrantz and Jan-Olof Yxell at Chalmers. Important results from the INNOTRACK deliverables are accounted for in a compact form. Separately, the Executive Summary (13 pages) has been translated into French, German, Russian and Swedish with CHARMEC contributing to the Russian and Swedish versions. All 144 deliverables are listed in the report, as are the partners of INNOTRACK.

Banedanmark

Researchers from CHARMEC have met with representatives of Banedanmark on several occasions to discuss, among other things, wheel damage and low-noise sleepers.

Indian Railways

On the initiative of UIC Asia, meetings have taken place in Sweden and India between representatives of CHARMEC and India's RDSO (Research Designs & Standards Organisation, Ministry of Railways) concerning our research results, in particular on concrete sleepers where Abetong has contributed, see project SP23 in the previous section.

Russian Railways

During Stage 6, meetings between representatives of CHARMEC and various actors at the Russian railways (RZD) on possible technology transfer have been had. On 15 December 2010, Dr Efim Rozenberg of the institute VNIIAS in Moscow visited Chalmers in a meeting organized by Anders Drott and Lars Lind. Among other topics, the planned 660 km high-speed line between Moscow and St Petersburg was discussed. On 4 April 2011, a meeting was held in Stockholm between the October Railway in St Petersburg (part of RZD) and Trafikverket with CHARMEC's Anders Ekberg and Elena Kabo taking part.

High-speed railways

Roger Lundén and Bengt Åkesson have taken part in seminars arranged in Gothenburg and Oslo on future high-speed lines in Sweden and Norway. In particular, the EU project COINCO North dealing with the distance Oslo-Gothenburg-Copenhagen (and further via Fehmarn Belt to Germany) has been discussed.

IVA and VH seminar 21 February 2012

A seminar titled "Järnväg i väst – stambanor OCH höghastighetsbanor" (Railways in western Sweden – existing main lines AND future high-speed lines) was held at Chalmers on 21 February 2012 under the auspices of Kungliga Ingenjörsvetenskapsakademien, IVA (the Royal Swedish Academy of Engineering Sciences), and Västsvenska Handelskammaren, VH (West Sweden Chamber of Commerce). CHARMEC's Bengt Åkesson was a member of the IVA group that planned and organized the seminar. Among the speakers were CHARMEC's Roger Lundén, Bombardier Transportation's Klas Wåhlberg, KTH's Bo-Lennart Nelldal, Jernbaneverket's Tom Stillesby (Norway), COINCO North's Floire Daub (Norway), Trafikverket's Lena Erixon, and the Swedish Minister for Infrastructure, Catharina Elmsäter-Svärd. Close to 450 people attended the seminar. An account of the presentations has been published (in Swedish) by Hans Cedermark, Christer Wannheden and Bengt Åkesson in the Swedish periodical Samhällsbyggaren 2012, no 3, pp 22-25.

KVVS

At the KVVS meeting on 14 March 2011, Roger Lundén delivered an address entitled "Som på räls – svensk järnvägsforskning" (As on rails – Swedish railway research; in Swedish). The acronym KVVS stands for Kungl. Vetenskaps- och Vitterhets-Samhället i Göteborg (the Royal Society of Arts and Sciences i Gothenburg) where Roger Lundén is a member.

Operational reliability

In connection with the Board meeting at Chalmers on 14 September 2011, an open seminar was announced and arranged with the theme "Driftsäkerhet inom järnvägen – järnvägsmekaniska aspekter / Operational reliability within the railway – railway mechanical aspects". Following an introduction where implementations from INNOTRACK, see project EU10, were illustrated, results from the CHARMEC projects MU18, MU26 and MU27 were presented.

Transport safety

A seminar on transport safety was held at Chalmers on 27 September 2011 within the Transport Area of Advance. Representatives from CHARMEC took part in this seminar. Hugo von Bahr of Interfleet Technology and Lennart Warsén of SJ presented the investigation made into the accident involving a collapsed wheel on a passenger train at Skotterud (Norway) on 1 October 2010. Anders Ekberg, Mikael Hägg, Monica Lundh, Deborah Mitchell, Jonas Ringsberg and Mats Svensson have compiled the document "Transport safety – research at Chalmers today and in the future" (Chalmers Applied Mechanics, Gothenburg 2011, 66 pp). A CHARMEC study of ten-year statistics in Sweden shows that the risk of a fatal accident is about

100 times lower per passenger-kilometre for people on board a train than for those travelling in road vehicles.

Winter problems

The winters of 2009/2010 and 2010/2011 were exceptionally harsh in Sweden and much of the country's railway traffic came to a halt. Measures to handle frozen switches and other problems relating to snow and ice have been discussed within CHARMEC. As reported in project MU22, Anders Ekberg from CHARMEC and Roger Deuce from Bombardier Transportation in Siegen (Germany) took part in the UIC winter seminar in Stockholm on 3 May 2011 and delivered a lecture titled "Impact of winter conditions on mechanical rail and wheel deterioration". In Oslo (Norway) on 5 May 2011, Anders Ekberg participated in a meeting within the Nordic "Wheel network" and spoke about "Materialutfall på godsvognhjul ved vinterdrift / Material loss on freight wagon wheels in winter traffic". CHARMEC has also taken part in a proposal for a new EU project on increased reliability of switches under winter conditions.

UTMIS

This acronym stands for Utmattningsnätverket i Sverige (the Fatigue Network in Sweden) and includes people from several branches of engineering, including railway mechanics. For instance, among the participants in the UTMIS course "Contact fatigue – initiation and growth of short cracks in complex stress fields" at Volvo Cars in Gothenburg on 29-30 September 2011 were CHARMEC's Johan Ahlström, Sara Caprioli, Krste Cvetkovski, Anders Ekberg, Elena Kabo, Kalle Karttunen, Nasim Larijani, Gaël Le Gigan, Christer Persson, Martin Schilke and Shahab Teimourimanesh. The course lecturer was Professor David Nowell from the University of Oxford in the UK.

External consultants and employees

It has only been partly possible for our PhD students to include CHARMEC's EU projects in their regular programme of studies and research. Instead, senior researchers have been required to contribute to EU and other projects at short notice. Chalmers/CHARMEC consequently engaged Dr Anders Johansson of Epsilon AB as an external part-time consultant during Stage 6. Professor Jens Nielsen, Dr Tore Vernersson and Docent Elena Kabo from the same consultancy firm have carried out research and supervision for CHARMEC on a full-time basis. Elena Kabo has later changed her affiliation to Qamcom Research & Technology AB.

In October 2010, the former external consultant Anders Ekberg left Chalmers Industriteknik (CIT) for a full-time post as salaried Docent in the Department of Applied Mechanics at Chalmers University of Technology. His specimen lecture on 9 June 2010 had the title "Railway mechanics and rolling contact fatigue".

Guests

Visitors to CHARMEC during Stage 6 have included Dr Motohide Matsui and Dr Toru Miyauchi from RTRI (see above) in Japan. Mr Zhigang Cao from Zhejiang University in Hangzhou (China) has been a PhD student at the Department of Applied Mechanics in a parallel project dealing with ground vibrations caused by high-speed trains, see project VB8. Several shorter visits have been paid to CHARMEC. For instance, in connection with Sara Caprioli's licentiate seminar, Steven Cervello of Lucchini RS in Italy gave a seminar titled "Innovations in railway wheelsets".

Passenger safety on railways

This issue has been discussed at CHARMEC's Board meetings during Stage 6. As mentioned above, Swedish statistics on death rates over the last decade show that the safety per passenger-kilometre for people onboard a train is about 100 times higher than for those travelling in road vehicles. Data from SIKA (the Swedish institute for communication analysis) were used. SIKA ceased to be a government agency in April 2010 and its activities were transferred to the new agencies Trafikverket and Trafikanalys.

Associated project AP4

Since April 2010, the doctoral student Gaël Le Gigan from France works at CHARMEC in the associated project AP4 "Improved performance of brake discs". This project is supported by VINNOVA and relates to brake discs used by the truck manufacturer Scania in Södertälje (Sweden). There are mutual synergy effects with CHARMEC's brake projects for railway vehicles, see photo on page 81.

Birgitta Johanson and Pernilla Appelgren

At the end of April 2011, Birgitta Johanson retired from her position as administrator and secretary at the Department of Applied Mechanics at Chalmers. She was recruited by Bengt Åkesson in 1992 and CHARMEC has benefitted from her outstanding services since the centre's start in 1995. Birgitta Johanson was acknowledged for her achievements at a leaving ceremony. CHARMEC welcomes her successor Pernilla Appelgren.

This is a presentation of the cash and in-kind investments for Stage 6, both per party and per programme area. Information about the money received and used is from Chalmers' accounts for the CHARMEC Competence Centre, and the accounts for each department's CHARMEC projects. The in-kind investments from Banverket/Trafikverket, the Industrial Interests Group and Chalmers have been calculated according to the principles stated in the Principal Agreement for Stage 6 dated 6 June 2009. Note that Banverket ceased on 1 April 2010 and that its duties then were taken over by the new governmental agency Trafikverket.

Report per party

Budgeted cash and in-kind investments per party according to the Principal Agreement for Stage 6 are presented in Table 1. Included are also cash contributions from Chalmers, Trafikverket, DB, VINNOVA and UIC that were not included in the Principal Agreement for Stage 6. Cash contributions from the EU and VR are also included although they are not a formal part of CHARMEC's budget.

Cash investments

A letter dated 19 September 2009 from CHARMEC to each of the following: Banverket, Abetong Teknik AB, Bombardier Transportation Sweden AB, Faiveley Transport Nordic AB, Green Cargo AB, Interfleet Technology AB, Lucchini Sweden AB, SJ AB, AB Storstockholms Lokaltrafik (SL), SweMaint AB and voestalpine Bahnsysteme GmbH & CoKG, proposed how the payments from the partners to CHARMEC should be settled. According to the letter, CHARMEC would invoice on six different occasions: 2009-10-01, 2010-03-01, 2010-09-01, 2011-03-01, 2011-09-01 and 2012-03-01. This proposal was accepted by all partners.

In January 2006, VINNOVA approved two project proposals from CHARMECproviding 50 % funding for the three doctoral projects TS11 "Rail corrugation growth on curves", VB10 "External noise generation from trains" and MU18 "Wheels and rails at high speeds and axle loads". The total amount is kSEK 6 000, of which kSEK 625 were paid during Stage 4 and kSEK 4 975 during Stage 5. The remaining kSEK 400 were paid during Stage 6.

In November 2008, The Swedish Research Council (VR) approved a project proposal from Chalmers/CHARMEC funding the doctoral project MU25 "Thermodynamically coupled contact between wheel and rail" where VR would contribute kSEK 2 400. The VR funding does not formally belong to CHARMEC's budget.

Table 1. Cash and in-kind contributions (kSEK) per party during Stage 6

Party	Cash		In-kind		Total	
	Budget	Paid	Budget	Performed	Budget	Paid/Perf
Chalmers	13 150	13 150	9 000	9 000	22 150	22 150
Abetong	1 320	1 320	600	418	1 920	1 738
Bombardier	2 310	2 310	1 200	1 475	3 510	3 785
Faiveley	1 050	1 050	600	305	1 650	1 355
Green Cargo	390	390	210	0	600	390
Interfleet	165	165	150	616	315	781
Lucchini	1 350	1 350	900	562	2 250	1 912
SJ	600	600	0	0	600	600
SL	1 320	1 320	330	393	1 650	1 713
SweMaint	150	150	150	40	300	190
Trafikverket	16 380	15 831	1 500	1 350	17 880	17 181
voestalpine	2 145	2 145	2 550	2 867	4 695	5 012
DB	150	150	-	-	150	150
EU	2 285	2 285	-	-	2 285	2 285
UIC	400	400	-	-	400	400
VINNOVA	400	400	-	-	400	400
VR	2 400	2 400	-	-	2 400	2 400
From Stage 5	5 074	5 074	-	-	5 074	5 074
Total	51 039	50 490	17 190	17 026	68 229	67 516

Note The funding from EU and VR does not formally belong to CHARMEC's budget

An agreement was reached in November 2009 between CHARMEC and Banverket concerning the SP19 project "Optimum track stiffness" where Banverket would contribute kSEK 600. In December 2009, Banverket approved a project proposal from CHARMEC providing funding for the doctoral projects TS13 "Optimization of track switches". The total amount is kSEK 2 125 of which the full amount was paid during Stage 6. In February 2010 Banverket proposed the SP22 project "Implementing INNOTRACK results at Trafikverket". A preliminary budget of kSEK 500 was planned but the budget was never approved. However, some urgent activities were performed and have been invoiced (kSEK 86).

In October 2010, it was agreed that each of Banverket and DB Netz AG would contribute kSEK 150 to the SP21 project "Optimum material selection for track switches". In October 2010, it was agreed that UIC would contribute kEUR 43 to the SP23 project "Optimized prestressed concrete sleeper". In December 2010, the EU approved a project proposal from Chalmers/CHARMEC and our European partners providing kEUR 225 to the EU12 project "RIVAS". The EU funding does not formally belong to CHARMEC's budget.

In April 2011, Trafikverket approved a project proposal from Luleå Technical University (LTU) providing three years of funding for two parallel doctoral projects on track switches, one at LTU and one at Chalmers/CHARMEC. The project at CHARMEC is TS15 "Improved availability and reduced life cycle cost of track switches" with a total budget (three years) of kSEK 2 865, of which 865 kSEK are assigned to Stage 6 and the remaining amount, kSEK 2 000, to Stage 7. It is anticipated that Trafikverket will later approve funding for the remaining two years of the two five-year doctoral projects. At the end of Stage 6, only kSEK 730 of the kSEK 865 had been invoiced by CHARMEC.

In September 2011, the EU approved a project proposal from Chalmers/CHARMEC and our European partners providing kEUR 250 to the EU13 project "D-RAIL". The EU funding does not formally belong to CHARMEC's budget. In December 2011, it was agreed that Trafikverket would contribute kSEK 140 to the SP25 project "Harmonized measurement sites for track forces". The project is also to receive funding from UIC.

Chalmers University supports CHARMEC financially. For Stage 6, the agreed amount was kSEK 2 750 from Chalmers centrally, kSEK 2 000 from the Department of Applied Mechanics centrally, kSEK 2 250 from its Division of Dynamics and kSEK 2 250 from its Division of Material and Computational Mechanics. The Department of Materials and Manu-

Table 2. Budgeted and used cash and in-kind contributions (kSEK) during Stage 6, with the Industrial Interests Group (including Banverket/Trafikverket) and Chalmers shown separately, for each programme area and for management and administration. CHARMEC's programme areas for Stage 6 are TS = Interaction of train and track, VB = Vibrations and noise, MU = Materials and maintenance, SD = Systems for monitoring and operation, EU = Parallel EU projects, and SP = Parallel special projects

Programme area	Cash		In-kind industry		In-kind Chalmers		Total	
	Budget	Used	Budget	Used	Budget	Used	Budget	Used
TS	10 665	11 227	1 750	1 822	1 565	1 565	13 980	14 614
VB	2 850	2 097	400	1 613	720	720	3 970	4 430
MU	21 100	22 656	3 250	2 414	5010	5 010	29 360	30 080
SD	5 650	6 580	1 450	731	760	760	7 860	8 071
EU	3 285	1 376	-	71	220	220	3 505	1 667
SP	2 390	1 683	200	1 375	0	0	2 590	3 058
Management	3 700	3 913	-	-	725	725	4 425	4 638
TOTAL	49 640	49 532	7 050	8 026	9 000	9 000	65 690	66 558

Note 1 Budget under "Cash" is as of 2 May 2012 and may later be revised by the CHARMEC Board

Note 2 Programme area SP includes kSEK 200 in cash for conference IWRN11

Note 3 The preliminary balance in cash to be transferred to CHARMEC's Stage 7 by 30 June 2012 is kSEK 51 039 – 49 640 = kSEK 1 399. However, the amount actually transferred to the projects is less than the budgeted kSEK 48 840 and it is anticipated that when the CHARMEC Board has revised the budget, the balance to be transferred to CHARMEC's Stage 7 will be about kSEK 3 000

Note 4 Projects EU10, SP16, SP17 and SP18 were partly run into Stage 6 but are not reported here since they have been referred to Stage 5 facturing Technology contributed kSEK 1 350. The Division of Technical Acoustics in the Department of Civil and Environmental Engineering contributed kSEK 450. Chalmers also agreed to contribute kSEK 2 100 during Stage 6 to the SD6 project "Adaptronics for bogies and other railway components" and the SD9 project "Multi-objective optimization of bogie system and vibration control" from a donation.

The following amounts in cash, totalling kSEK 26 481, due for CHARMEC's Stage 6 have been received as per agreements:

6 × kSEK 220	Abetong Teknik
6 × kSEK 2000+kSEK (600+2 125+86+150+730+140)	
= kSEK 15 831	Banverket/Trafikverket
6 × kSEK 385	Bombardier Transportation Sweden
6 × kSEK 175	Faiveley Transport Nordic
6 × kSEK 65	Green Cargo
6 × kSEK 27.5	Interfleet Technology
6 × kSEK 225	Lucchini Sweden
6 × kSEK 100	SJ
6 × kSEK 220	SL
6 × kSEK 25	SweMaint
6 × kSEK 357.5	voestalpine Bahnsysteme

From VINNOVA, kSEK 400 in cash have been received for project MU18. From VR, kSEK 2 400 in cash have been received for project MU25. From DB Netz AG, kSEK 150 in cash have been received for project SP21. From UIC, kSEK 400 (kEUR 43) in cash have been received for project SP23. From EU, kSEK 1 505 + 780 = kSEK 2 285 in cash have been received for projects EU12 and EU13. Finally, kSEK 2 750 + 2 000 + 2 550 + 1 950 + 1 350 + 450 + 2 100 = kSEK 13 150 have been received from Chalmers. The total amounts are shown in Table 1.

In-kind contributions

The in-kind contributions made by Banverket/Trafikverket and the Industrial Interests Group correspond well to the agreement for Stage 6, see Table 1. The work performed is presented briefly in the section "Projects and results". The in-kind contributions have been returned on a form from CHARMEC, which the partner concerned has completed and signed. NUTEK's guidelines as of 1995-11-07 were enclosed with the form. Salary costs (number of hours and hourly rates) and other costs (use of machines, materials and computers, travel expenses, services purchased, etc) are shown on the form. All costs relate to the CHARMEC projects specified in the current report.

Part of the in-kind contributions from Chalmers originate from the Transport Area of Advance at Chalmers and have not been shown separately. For Stage 7, the plan is for that these contributions will be reported separately.

Report per programme area

The accounts for each individual project have been allocated funds according to budgets decided by the CHARMEC Board. A compilation by programme area is given in Table 2, where in-kind contributions are also shown.

MANAGEMENT AND ADMINISTRATION

Director	Professor Roger Lundén
Period	1997-04-01–2012-06-30 (–2015-06-30)
Chalmers budget (excluding university basic resources)	Stage 1: kSEK 1 084 Stage 2: kSEK 4 000 Stage 3: kSEK 4 400 Stage 4: kSEK 3 900 Stage 5: kSEK 3 900 Stage 6: kSEK 3 700 Stage 7: kSEK 3 900
Industrial interests in-kind budget and results, see pages 14-105	–

Roger Lundén has devoted approximately half of his full-time position to the management and administration of the CHARMEC Competence Centre during Stage 6, and the rest of his time to duties as teacher, researcher and research supervisor in Applied Mechanics. From 1 October 2012, Roger Lundén will be succeeded by Docent Anders Ekberg.

Bengt Åkesson, Professor Emeritus of Solid Mechanics and Director of CHARMEC until April 1997, has assisted in the organization and quality assessment of CHARMEC's research. Birgitta Johanson and Pernilla Appelgren from Chalmers Applied Mechanics have assisted in the administration and have served as the Centre's secretaries.

CHARMEC STAGE 7

The Principal Agreement for CHARMEC's Stage 7 (1 July 2012 – 30 June 2015) complies with VINNOVA's Principal Agreement for the Centre's Stage 4. As with Stages 5 and 6, Trafikverket (then Banverket) has been included directly in the agreement for Stage 7 and partly holds the administrative role that was previously filled by VINNOVA. The rights and obligations of the three parties (Chalmers University of Technology, Trafikverket and the Industrial Interests Group) comply with the Principal Agreements for Stages 4, 5 and 6. In a supplementary agreement dated 23 August 2012, minor modifications of Trafikverket's terms were made.

The programme areas in Stage 7 are the same as during Stage 6, see TS, VB, MU, SD, EU and SP on page 11.

Funding (KSEK) for Stage 7 (as of 6 September 2012) is shown in the table below. It should be noted that the ten-year funding from national research agencies NUTEK and VINNOVA ceased as of 30 June 2005.

President of Chalmers University of Technology, Karin Markides, signed the contracts for Stage 7 on 19 June and 29 August 2012. She appointed the following board members for CHARMEC's Stage 7 (decision dated 29 August 2012):

Annika Renfors (chair)	Trafikverket
Rikard Bolmsvik	Abetong
Jakob Wingren	Bombardier Transportation
Jan Sterner	Faiveley Transport
Marcin Tubylewicz	Green Cargo
Hugo von Bahr	Interfleet Technology
Erik Kihlberg	Lucchini Sweden
Susanne Rymell	SJ
Robert Lagnebäck	Storstockholms Lokaltrafik (SL)
Per Gelang	SweMaint
Håkan Anderson	voestalpine Bahnsysteme
Sebastian Stichel	The Royal Institute of Technology (KTH)
Hans Andersson	Chalmers
Per Lövsund	Chalmers

For a photo of members of the new Board, see page 9.

On 29 August 2012, Karin Markides also appointed Roger Lundén as Director of CHARMEC for the period 1 July – 30 September 2012 and Anders Ekberg as new Director for the remainder of Stage 7.

	Cash	In-kind	Total
Industrial Interests Group	11 730	7 080	18 810
Trafikverket	15 000	1 500	16 500
Chalmers	12 180	8 000	20 180
Chalmers (donation)	3 000	–	3 000
Trafikverket (projects)	2 880	–	2 880
UIC (projects)	400	–	400
VINNOVA (projects)	400	–	400
EU (projects)*	2 255	–	2 255
From Stage 6	3 000	–	3 000
Total	50 845	16 580	67 425

* The funding from EU does not formally belong to CHARMEC's budget

CONCLUDING REMARKS

Stage 6 of the NUTEK/VINNOVA Competence Centre in Railway Mechanics has been successful. Co-operation between the university, industry and Banverket/Trafikverket has continued to develop, and national and international networks have been broadened. I believe that CHARMEC provides first-rate research, is a knowledgeable dialogue partner and an important information hub and expert network builder. As Railway Mechanics is key to the development of sustainable land transport both in Sweden and internationally, I look forward to Stage 7 with confidence. Our motto of "academic excellence combined with industrial relevance" will continue.

Gothenburg in September 2012

Roger Lundén

ROGER LUNDÉN

TS Interaction of train and track
Programme area 1

TS1 Calculation models of track structures[3]
Prof Thomas Abrahamsson / Doc Jens Nielsen
Mr Johan Oscarsson[2]

TS2 Railhead corrugation formation[3]
Prof Tore Dahlberg[4]
Ms Annika Igeland[2] (now Annika Lundberg)

TS3 Sleeper and railpad dynamics[3]
Prof Tore Dahlberg[4]
Ms Åsa Fenander[2] (now Åsa Sällström)

TS4 Lateral track dynamics[3]
Prof Thomas Abrahamsson / Doc Jens Nielsen
Mr Clas Andersson[2]

TS5 Out-of-round wheels – causes and consequences[3]
Doc Jens Nielsen / Prof Roger Lundén
Mr Anders Johansson[2]

TS6 Identification of dynamic forces in trains[3]
Prof Thomas Abrahamsson / Dr Peter Möller
Mr Lars Nordström[2]

TS7 Dynamics of track switches[3]
Prof Jens Nielsen / Prof Tore Dahlberg[4]
Mr Elias Kassa[2]

TS8 Integrated track dynamics
Prof Jens Nielsen

TS9 Track dynamics and sleepers
Prof Thomas Abrahamsson / Prof Jens Nielsen
Ms Johanna Lilja[1]

TS10 Track response when using Under Sleeper Pads (USP)
Dr Rikard Bolmsvik / Prof Jens Nielsen

TS (cont'd)

TS11 Rail corrugation growth on curves
Prof Jens Nielsen / Dr Anders Frid
Mr Peter Torstensson[1]

TS12 Identification of wheel–rail contact forces[3]
Doc Fredrik Larsson / Dr Håkan Johansson / Prof Kenneth Runesson / Dr Peter Möller / Prof Jens Nielsen
Mr Hamed Ronasi[2]

TS13 Optimization of track switches
Prof Jens Nielsen / Prof Thomas Abrahamsson
Mr Björn Pålsson[1]

TS14 Multicriterion optimization of track properties
Prof Thomas Abrahamsson / Prof Jens Nielsen
Mr Sadegh Rahrovani

TS15 Improved availability and reduced life cycle cost of track switches
Prof Jens Nielsen / Prof Magnus Ekh
Ms Xin Li

Upper name(s):
Project leader(s) and supervisor(s)

Lower name(s):
Doctoral candidate(s) or other co-worker(s)

The abbreviation *Doc* is used for *Docent* which is the highest academic qualification in Sweden (above the doctor's level)

Departments involved at Chalmers:
Applied Mechanics
Civil and Environmental Engineering
Materials and Manufacturing Technology
Mathematical Sciences
Signals and Systems

VB11 Abatement of curve squeal noise from trains
Prof Wolfgang Kropp / Dr Astrid Pieringer
Mr Ivan Zenzerovic

VB12 High-frequency wheel–rail interaction
Dr Astrid Pieringer / Prof Wolfgang Kropp

VB Vibrations and noise
Programme area 2

VB1 Structural vibrations from railway traffic[3]
Prof Sven Ohlsson / Prof Thomas Abrahamsson
Mr Johan Jonsson[2]

VB2 Noise from tread braked railway vehicles
Prof Roger Lundén / Dr Peter Möller
Mr Tore Vernersson[2] / Mr Martin Petersson[1]

VB3 Test rig for railway noise[3]
Prof Roger Lundén
Mr Tore Vernersson

VB4 Vibrations and external noise from train and track[3]
Prof Roger Lundén / Dr Anders Frid / Doc Jens Nielsen
Mr Carl Fredrik Hartung[1]

VB5 Wave propagation under high-speed trains[3]
Prof Nils-Erik Wiberg
Mr Torbjörn Ekevid[2]

VB6 Interaction of train, soil and buildings[3]
Dr Johan Jonsson

VB7 Vibration transmission in railway vehicles[3]
Prof Thomas Abrahamsson / Prof Tomas McKelvey
Mr Per Sjövall[2]

VB8 Ground vibrations from railways[3]
Prof Anders Boström / Prof Thomas Abrahamsson
Mr Anders Karlström[2]

VB9 Dynamics of railway systems[3]
Prof Nils-Erik Wiberg / Dr Torbjörn Ekevid
Mr Håkan Lane[2]

VB10 External noise generation from trains[3]
Prof Wolfgang Kropp
Ms Astrid Pieringer[2]

MU Materials and maintenance
Programme area 3

MU1 — **Mechanical properties of ballast**[3]
Prof Kenneth Runesson
Mr Lars Jacobsson[1]

MU2 — **New materials in wheels and rails**[3]
Prof Birger Karlsson
Mr Johan Ahlström[2]

MU3 — **Martensite formation and damage around railway wheel flats**[3]
Prof Roger Lundén
Mr Johan Jergéus[2]

MU4 — **Prediction of lifetime of railway wheels**[3]
Prof Roger Lundén
Mr Anders Ekberg[2]

MU5 — **Mechanical properties of concrete sleepers**[3]
Prof Kent Gylltoft
Mr Rikard Gustavson[2] *(now Rikard Bolmsvik)*

MU6 — **Rolling contact fatigue of rails**[3]
Prof Lennart Josefson
Mr Jonas Ringsberg[2]

MU7 — **Laser treatment of wheels and rails**[3]
Prof Birger Karlsson
Mr Simon Niederhauser[2]

MU8 — **Butt-welding of rails**[3]
Prof Lennart Josefson / Doc Jonas Ringsberg
Mr Anders Skyttebol[2]

MU9 — **Rolling contact fatigue of railway wheels**[3]
Doc Anders Ekberg/Dr Elena Kabo
Prof Roger Lundén

MU10 — **Crack propagation in railway wheels**[3]
Prof Hans Andersson /
Dr Elena Kabo / Doc Anders Ekberg
Ms Eka Lansler[1]

MU (cont'd)

MU11 — **Early crack growth in rails**[3]
Prof Lennart Josefson / Doc Jonas Ringsberg /
Prof Kenneth Runesson
Mr Anders Bergkvist[1]

MU12 — **Contact and crack mechanics for rails**[3]
Prof Peter Hansbo
Mr Per Heintz[2]

MU13 — **Wheel and rail materials at low temperatures**[3]
Dr Johan Ahlström / Prof Birger Karlsson

MU14 — **Damage in track switches**[3]
Doc Magnus Ekh / Prof Kenneth Runesson
Mr Göran Johansson[2]

MU15 — **Microstructural development during laser coating**[3]
Prof Birger Karlsson / Dr Johan Ahlström

MU16 — **Alternative materials for wheels and rails**[3]
Dr Johan Ahlström / Prof Birger Karlsson
Mr Niklas Köppen[1]

MU17 — **Elastoplastic crack propagation in rails**[3]
Doc Fredrik Larsson / Prof Kenneth Runesson /
Prof Lennart Josefson
Mr Johan Tillberg[2]

MU18 — **Wheels and rails at high speeds and axle loads**[3]
Doc Anders Ekberg / Prof Lennart Josefson /
Prof Kenneth Runesson / Prof Jacques de Maré
Mr Johan Sandström[2]

MU19 — **Material anisotropy and RCF**[6] **of rails and switches**
Prof Magnus Ekh / Prof Kenneth Runesson /
Doc Anders Ekberg
Ms Nasim Larijani[1]

MU20 — **Wear impact on RCF**[6] **of rails**
Prof Magnus Ekh / Doc Fredrik Larsson /
Doc Anders Ekberg
Mr Jim Brouzoulis[1]

MU (cont'd)

MU21 — **Thermal impact on RCF**[6] **of wheels**
Doc Anders Ekberg / Doc Elena Kabo /
Prof Magnus Ekh / Dr Tore Vernersson
Ms Sara Caprioli[1]

MU22 — **Improved criterion for surface initiated RCF**[6]
Doc Anders Ekberg /
Doc Elena Kabo / Prof Roger Lundén

MU23 — **Material behaviour at rapid thermal processes**
Doc Johan Ahlström / Prof Christer Persson
Mr Krste Cvetkovski[1]

MU24 — **High-strength steels for railway rails**
Prof Christer Persson / Prof Magnus Ekh
Mr Martin Schilke[1]

MU25 — **Thermodynamically coupled contact between wheel and rail**
Doc Anders Ekberg / Doc Fredrik Larsson /
Prof Kenneth Runesson
Mr Andreas Draganis[1]

MU26 — **Optimum inspection and maintenance of rails and wheels**
Doc Ann-Brith Strömberg / Doc Anders Ekberg /
Prof Michael Patriksson
Mr Emil Gustavsson

MU27 — **Progressive degradation of rails and wheels**
Doc Elena Kabo / Doc Anders Ekberg /
Prof Michael Patriksson
Mr Kalle Karttunen

Notes:
1. Licentiate (teknologie licentiat)
2. PhD (teknologie doktor)
3. This project has been finished
4. Later at Linköping Institute of Technology
5. Doctoral candidate to be recruited
6. Rolling Contact Fatigue

SD Systems for monitoring and operation
Programme area 4

- **SD1** **Braking of freight trains – a systems approach**[3] — *Prof Göran Gerbert, Mr Daniel Thuresson*[2]
- **SD2** **Sonar pulses for braking control**[3] — *Prof Bengt Schmidtbauer / Mr Hans Sandholt*
- **SD3** **Computer control of braking systems for freight trains**[3] — *Mr Håkan Edler / Prof Jan Torin, Mr Roger Johansson*[2]
- **SD4** **Control of block braking**[3] — *Prof Roger Lundén, Mr Tore Vernersson*[2]
- **SD5** **Active and semi-active systems in railway vehicles**[3] — *Prof Jonas Sjöberg / Prof Thomas Abrahamsson, Ms Jessica Fagerlund*[1]
- **SD6** **Adaptronics for bogies and other railway components**[3] — *Prof Viktor Berbyuk / Doc Mikael Enelund, Mr Albin Johnsson*[1]
- **SD7** **Thermal capacity of tread braked railway wheels** — *Prof Roger Lundén / Dr Tore Vernersson, Mr Shahab Teimourimanesh*[1]
- **SD8** **Wear of disc brakes and block brakes** — *Dr Tore Vernersson / Prof Roger Lundén*
- **SD9** **Multiobjective optimization of bogie system and vibration control** — *Prof Viktor Berbyuk, Mr Milad Mousavi*

All projects SP1-SP25 are reported on pages 92-105

EU Parallel EU projects
Programme area 5

- **EU1** **EuroSABOT**[3] — *Prof Roger Lundén, Mr Tore Vernersson / Mr Martin Petersson*
- **EU2** **Silent Freight**[3] — *Dr Jens Nielsen, Mr Martin Petersson / Mr Markus Wallentin*
- **EU3** **Silent Track**[3] — *Dr Jens Nielsen, Mr Clas Andersson*
- **EU4** **ICON**[3] — *Prof Lennart Josefson, Mr Jonas Ringsberg*
- **EU5** **EuroBALT II**[3] — *Prof Tore Dahlberg*[4]*, Mr Johan Oscarsson*
- **EU6** **HIPERWHEEL**[3] — *Prof Roger Lundén, Doc Jens Nielsen/Dr Anders Ekberg*
- **EU7** **INFRASTAR**[3] — *Prof Lennart Josefson / Prof Roger Lundén, Doc Jens Nielsen / Dr Jonas Ringsberg / Prof Birger Karlsson*
- **EU8** **ERS**[3] — *Prof Roger Lundén, Mr Martin Helgen / Doc Jan Henrik Sällström / Mr Tore Vernersson*
- **EU9** **EURNEX** — *Prof Roger Lundén, Doc Anders Ekberg*
- **EU10** **INNOTRACK**[3] — *Prof Roger Lundén / Doc Anders Ekberg and co-workers*
- **EU11** **QCITY**[3] — *Prof Jens Nielsen*
- **EU12** **RIVAS** — *Prof Jens Nielsen and co-workers*
- **EU13** **D-RAIL** — *Doc Anders Ekberg and co-workers*

SP Parallel special projects
Programme area 6

- **SP7** **Lateral track stability**
- **SP8** **Design of insulated joints**
- **SP9** **Sleeper design for 30 tonne axle load**
- **SP10** **Noise reduction measures and EU project QCITY**
- **SP11** **Vertical contact forces of high-speed trains**
- **SP12** **New sleeper specifications**
- **SP13** **Alarm limits for wheel damage**
- **SP14** **Particle emissions and noise from railways**
- **SP15** **Computer program for design of block brakes**
- **SP16** **Identification of dynamic properties in track of timber sleepers and concrete replacement sleepers**
- **SP17** **Switch sleeper specifications**
- **SP18** **Ground vibrations from railway traffic – a prestudy on the influence of vehicle parameters**
- **SP19** **Optimum track stiffness**
- **SP20** **Classification of wheel damage forms**
- **SP21** **Optimum material selection for track switches**
- **SP22** **Implementing INNOTRACK results at Trafikverket**
- **SP23** **Optimized prestressed concrete sleeper**
- **SP24** **Derailment risks in switches**
- **SP25** **Harmonized measurement sites for track forces**

Departments and research groups/divisions/areas

APPLIED INFORMATION TECHNOLOGY
Interaction design
IT Management
IT and Innovation
Cognitive Science
Communication
Learning
Public Safety and Crisis Management
Visualisation

APPLIED MECHANICS
Combustion
Dynamics
Fluid Dynamics
Material and Computational Mechanics
Vehicle Engineering and Autonomous Systems
Vehicle Safety

APPLIED PHYSICS
Biological Physics
Bionanophotonics
Chemical Physics
Condensed Matter Physics
Condensed Matter Theory
Materials and Surface Theory
Microscopy and Microanalysis
Nuclear Engineering
Solid State Physics

ARCHITECTURE
Architecture Theory and History
Conservation and Transformation
Matter, Space, Structure
Modelling and Visualization
Space and Activity
Urban Design and Development

CHEMICAL AND BIOLOGICAL ENGINEERING
Analytical Chemistry
Applied Surface Chemistry
Biopolymer Technology
Chemical Engineering Design
Chemical Environmental Science
Chemical Reaction Engineering
Environmental Inorganic Chemistry
Food Science
Forest Products and Chemical Engineering
Industrial Biotechnology
Industrial Materials Recycling
Molecular Imaging
Nuclear Chemistry
Organic Chemistry
Pharmaceutical Technology
Physical Chemistry
Polymer Technology
Systems Biology

CIVIL AND ENVIRONMENTAL ENGINEERING
Applied Acoustics
Building Technology
Construction Management
GeoEngineering
Structural Engineering
Water Environment Technology

COMPUTER SCIENCE AND ENGINEERING
Computer Engineering
Computing Science
Networks and Systems
Software Engineering
Software Technology

EARTH AND SPACE SCIENCE
Advanced Receiver Development
Global Environmental Measurements and Modelling
Nonlinear Electrodynamics
Optical Remote Sensing
Radar Remote Sensing
Radio Astronomy and Astrophysics
Space Geodesy and Geodynamics
Transport Theory
Onsala Space Observatory (National facility for radio astronomy)

ENERGY AND ENVIRONMENT
Building Services Engineering
Electric Power Engineering
Energy Technology
Environmental Systems Analysis
Heat and Power Technology
Physical Resource Theory

FUNDAMENTAL PHYSICS
Elementary Particle Physics
Mathematical Physics
Subatomic Physics

MATERIALS AND MANUFACTURING TECHNOLOGY
Advanced Non-destructive Testing
High Voltage Engineering
Manufacturing Technology
Materials Technology
Polymeric Materials and Composites
Surface and Microstructure Engineering

MATHEMATICAL SCIENCES
Mathematics
Mathematical Statistics

MICROTECHNOLOGY AND NANOSCIENCE
Applied Quantum Physics
BioNano Systems
Microwave Electronics
Nanofabrication
Photonics
Quantum Device Physics
Terahertz and Millimetre Wave Technology

PRODUCT AND PRODUCTION DEVELOPMENT
Design and Human Factors
Product Development
Production Systems

SHIPPING AND MARINE TECHNOLOGY
Ship Design
Ship Work Environment and Safety
Shipping Logistics and Chartering
Sustainable Ship Propulsion

SIGNALS AND SYSTEMS
Automatic Control, Automation and Mechatronics
Communication Systems, Information Theory and Antennas
Signal Processing and Biomedical Engineering

TECHNOLOGY MANAGEMENT AND ECONOMICS
Industrial Marketing
Innovation Engineering and Management
Logistics and Transportation
Management of Organisational Renewal and Entrepreneurship
Operations Management
Quality Sciences
Service Management
Technology and Society

Areas of Advance

Built Environment
Energy
Information and Communication Technology
Life Science
Materials Sciences
Nanoscience and Nanotechnology
Production
Transport

Educational programmes

ENGINEERING FOUNDATION PROGRAMME
Engineering preparatory year

BScEng AND BSc
Building and Civil Engineering
Business Strategy and Entrepreneurship in Building Technology
Chemical Engineering
Computer Engineering
Electrical Engineering
Economics and Manufacturing Technology
Marine Engineering
Mechanical Engineering
Mechatronics Engineering
Nautical Science
Product Design Engineering
Shipping and Logistics

MScEng AND MArch
Architecture
Architecture and Engineering
Automation and Mechatronics Engineering
Bio Engineering
Chemical Engineering
Chemical Engineering with Physics Engineering
Civil Engineering
Computer Science and Engineering
Electrical Engineering
Engineering Mathematics
Engineering Physics
Industrial Design Engineering
Industrial Enginering and Management
Mechanical Engineering
Software Engineering

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Chalmers Professional Education (CPE):
Executive Education
Industrial Engineering
Shipping
Energy

101

One hundred
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CHARMEC

Chalmers University of Technology
CHARMEC
SE-412 96 Gothenburg, Sweden

Telephone +46 31 772 1500
E-mail info.charmec@chalmers.se
Web www.chalmers.se/charmec

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