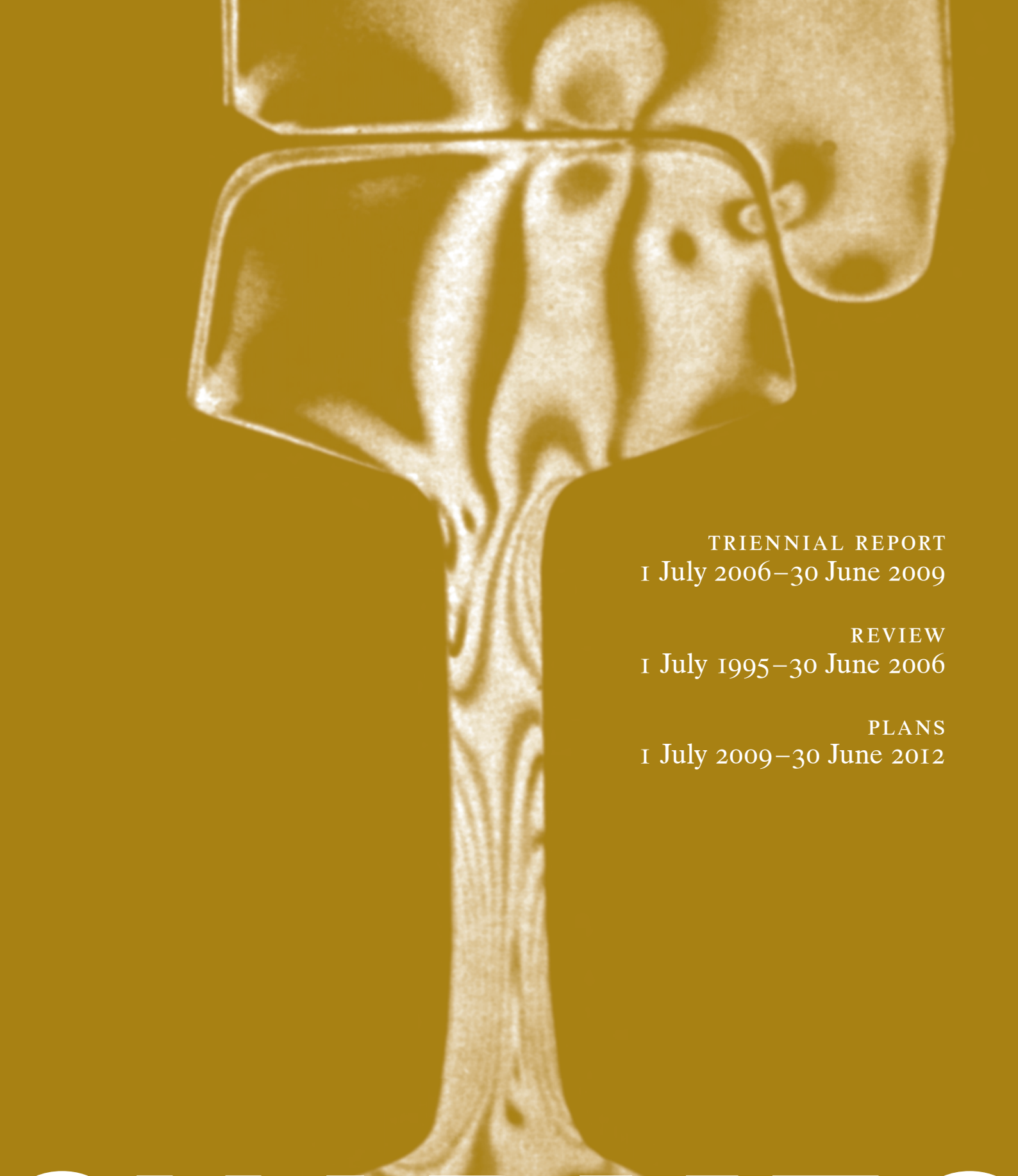


TRIENNIAL REPORT
1 July 2006–30 June 2009

REVIEW
1 July 1995–30 June 2006

PLANS
1 July 2009–30 June 2012

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 5 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 and 4 and a look forward at Stage 6 are also included.

The fold-out on pages 100-102 contains an overview of all CHARMEC projects (now 85) 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 2009

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

CONTENTS

from the Director

The demand for cutting-edge railway research has never been greater as the railway sector assumes more and more responsibility for efficient and sustainable transport. Increasing traffic volumes are accompanied by higher train speeds and greater axle loads, while time available for coping with maintenance, repairs and operational disturbances shrinks. The trial-and-error period is over. We need to know the consequences before we act.

In response, the railway sector is travelling down the same route as many other industries - computer simulations become standard practise and advanced simulations are employed for predictions and optimizations. The results of a simulation are never better than the combination of input data and numerical model, however. This is where CHARMEC comes in. On the following pages, we provide a glimpse of our research in a diversity of areas: rail materials, sleeper specifications, braking systems, wheel stresses, ground vibrations and noise emissions. The overriding discipline is railway mechanics, i e, the loading, deformation and wear of railway components and consequences thereof.

A high-level research centre takes around ten years to establish. This is no secret to the scientific world. CHARMEC has passed this phase and developed an arsenal of knowledge, tools and experience. The challenge now lies in maintaining scientific curiosity and striving forward, both of which come naturally to a young centre. We will stay true to our motto of combined academic excellence and industrial relevance. A key ingredient is communication: with the scientific community, by having our research reviewed and criticized; and with Banverket and our industrial partners, by having our relevance scrutinized and research translated into world-class products and practices. This publication is part of that continuing dialogue.

Finally, the strength of our progress lies in the talent and dedication of so many individuals. CHARMEC has been privileged to work with eminent industrial partners, doctoral students, senior researchers and colleagues from all over the world. Thanks to them, we know that the future of railways is bright! A particular challenge is the approaching introduction of high-speed train traffic in Sweden.

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

EXECUTIVE SUMMARY

The Swedish Governmental Agency for Innovation Systems (VINNOVA) organized a third international evaluation of CHARMEC at the end of the Centre's Stage 3. Two citations from the evaluators* are:

CHARMEC has established itself as an internationally recognized multidisciplinary Centre of Excellence in railway mechanics with a critical mass of senior research competence. Based on good project management and engineering expertise, excellent results are achieved on vital projects within the railway industry. CHARMEC has been recognized by its industry partners for its international contact network through which they obtain access to the global railway business. – Excellent scientific achievement is evident within the six Programme Areas of CHARMEC.

A new international evaluation administered by Banverket during the Centre's Stage 6 is now being discussed.

The Competence Centre *CH*Almers *R*ailway *ME*Chanics was established in July 1995 at Chalmers University of Technology in Gothenburg, Sweden. The annual budget during the three years of Stage 5 has been MSEK 24.7 (about MEUR 2.5), see page 96. Three parties have provided funding: Chalmers University of Technology, Banverket (the Swedish National Rail Administration), and an Industrial Interests Group comprising ten partners. In total, 30 ordinary research projects together with 3 EU projects and 11 development projects were conducted during Stage 5 within the six programme areas, see the fold-out on pages 100-102 and also page 11,

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

At Chalmers, 52 people (project leaders, academic supervisors, doctoral students and senior researchers) from 4 departments (out of a total 17 at Chalmers, see page 103) have been involved. They published 94 scientific papers in interntional journals and conference proceedings during Stage 5 (including those in print). Six Licentiate degrees and seven PhD degrees were conferred during Stage 5. A total of 34 Licentiate degrees and 26 PhD degrees in railway mechanics have been awarded to date (June 2009) at Chalmers, see page 80. Around 100 partners (industries, universities, institutes, public agencies, consultancies) from 19 countries have been involved in our three European projects during Stage 5.

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 and the Industrial Interests Group. Knowledge has been transferred in both directions through advisory groups and industrial site visits, regular seminars and brainstorming meetings as well as co-authored journal papers, co-ordinated conference participation and joint field experiment campaigns. The inertia dynamometer for braking experiments and the railway noise rig for acoustic measurements at the Lucchini Sweden plant site at Surahammar have been at our disposal, and the former has been used during Stage 5. Activities will continue during Stage 6.

* The evaluators were generalists Professor John S Baras (University of Maryland, USA), Professor Cesar Dopazo (SIEMAT Research Centre, Madrid, Spain) and Professor Per Stenius (Helsinki University of Technology, Finland) and specialists Dr Robert D Fröhling (Spoornet Engineering, RSA) and Professor Dudley Roach (Central Queensland University, Australia). See VINNOVA's Information Report VI 2003:4

Funding (MSEK) of CHARMEC during Stages 1 to 4 excluding EU projects and during Stages 5 and 6 including EU projects. Note that Stage 1 only lasted two years whereas the following Stages are for three years. The approximate exchange rate (September 2009) is 1 MSEK = 0.10 MEUR

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*			

* After Board Meeting on 28 May 2009

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 joint 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.

Jan-Eric Sundgren, President of Chalmers University, signed nine of the eleven contracts for CHARMEC's Stage 5 on 19 June 2006 which were then sent to and signed by Banverket and eight members of the Industrial Interests Group. On 19 September 2006, Karin Markides, new President of Chalmers University from 1 July 2006, signed the two remaining contracts for CHARMEC's Stage 5 which were then sent to and signed by the two members Green Cargo and SweMaint of the Industrial Interests Group.

A brief outline of CHARMEC's Stage 6 (1 July 2009 – 30 June 2012) is presented on page 99. 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 5 were:

Chalmers University of Technology

Banverket – the Swedish National Rail Administration (the government authority with combined overall responsibility for the railway infrastructure and rolling stock) 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 Malmö (now 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 (now 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, Banverket 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 focusses 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.

CHARMEC's secretary
Birgitta Johanson

BOARD AND DIRECTOR

Karin Markides, President of Chalmers University of Technology, in consultation with Banverket and the Industrial Interests Group, appointed the following people as members of the Board of the Competence Centre CHARMEC at the end of Stage 5 (decision dated 26 January 2009):

Tomas Ramstedt (chairman)	Banverket
Rikard Bolmsvik	Abetong
Henrik Tengstrand	Bombardier Transportation Sweden
Roger Jönsson	Faiveley Transport
Marcin Tubylewicz	Green Cargo
Hugo von Bahr	Interfleet Technology (and SJ)
Lennart Nordhall	Lucchini Sweden
Johan Oscarsson	SL Technology
Peter Linde	SweMaint / Kockums Industrier
Håkan Anderson	voestalpine Bahnsysteme
Stefan Östlund	The Royal Institute of Technology (KTH)
Hans Andersson	SP Technical Research Institute of Sweden (and Chalmers)

Björn Paulsson of Banverket resigned as member and chairman of the CHARMEC Board on 31 December 2008 and was succeeded by Tomas Ramstedt. Björn Paulsson had held these positions since the start of CHARMEC on 1 July 1995, see page 86. Stefan Westberg of Abetong resigned on 30 June 2008 and was then succeeded by Rikard Bolmsvik. Stefan Westberg had also been a member of the Board since 1 July 1995.

From November 2006, Håkan Fredriksson of SweMaint joined the Board. From November 2007, Johan Oscarsson of SL Technology replaced Håkan Tirus on the Board, and Helena Wetterwik of Green Cargo joined the Board. In September 2008, Peter Linde of Kockums Industrier (new owner of SweMaint) succeeded Håkan Fredriksson, and Marcin Tubylewics of Green Cargo joined the Board. The decisions on these changes by President Karin Markides of Chalmers University are dated 2006-11-15, 2007-11-19 and 2008-09-16.

Professor Roger Lundén of Chalmers Solid Mechanics (now 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 5, President Jan-Eric Sundgren appointed Roger Lundén in his decision dated 2006-06-19.

The Board of CHARMEC at its meeting on 19 February 2009 in William Chalmers' House (Södra Hamngatan 11, Gothenburg)

Roger Jönsson
of Faiveley
Transport (4+5)

Peter Linde
of SweMaint/Kockums
Industrier (5+6)

Håkan Anderson
of voestalpine
Bahnsysteme (4+5+6)

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

Standing (from the left)

Roger Lundén of Chalmers (Director of CHARMEC)

Bengt Åkesson of Chalmers (initiator and former Director of CHARMEC)

Lennart Nordhall of Lucchini Sweden (1+2+3+4+5)

Björn Paulsson of Banverket (former Chairman,1+2+3+4+5)

Hugo von Bahr of Interfleet Technology (1+2+3+4+5+6)

Marcin Tubylewics of Green Cargo (5+6)

Johan Oscarsson of SL Technology (5+6)

Anders Ekberg of Chalmers (senior researcher)

Seated (from the left)

Stefan Östlund of KTH (2+3+4+5)

Erik Kihlberg of Lucchini Sweden (6)

Hans Andersson of SP Technical Research Institute of Sweden (1+2+3+4+5+6)

Rikard Bolmsvik of Abetong (5+6)

Tomas Ramstedt of Banverket (Chairman, 5+6)

Henrik Tengstrand of Bombardier Transportation Sweden (3+4+5+6)

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:

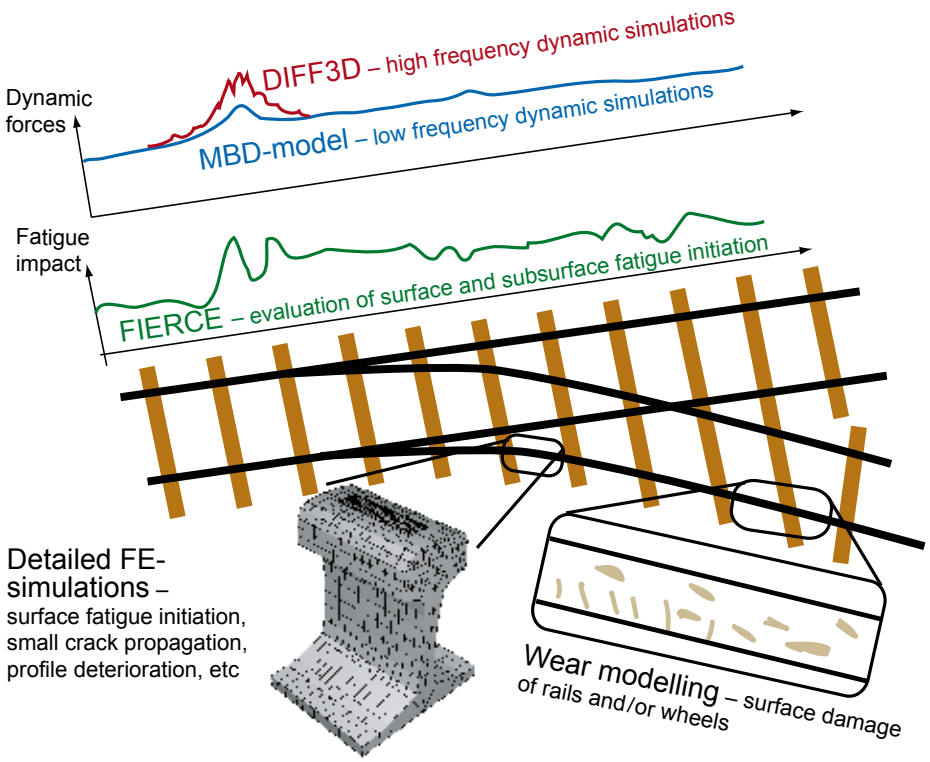
- The ability to understand, formulate and "make scientific" the current problems and aims of Banverket and the Industrial Interests Group
- The ability to initiate and run general future-oriented projects within the Centre's field of activity
- The publication of scientific works in recognized international 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 80)
- The transfer to Banverket 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 5, 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 Banverket 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 Banverket 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 Banverket or in the industry, either directly or through consulting companies.

Each individual research project within the Centre should correspond to five years of full-time 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 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 38

PROGRAMME AREAS CHARMEC STAGE 5

According to the Principal Agreement for Stage 5, 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 programme areas are the same as those during Stages 3 and 4.

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 5, Chalmers University of Technology has been a partner, through CHARMEC, in several EU (European Union) projects in railway mechanics within the Fourth, Fifth and Sixth 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 5

Research at the Centre during Stage 5 has been carried out as planned. The new members SJ AB and SweMaint AB have joined the Industrial Interests Group. The Board of CHARMEC met as follows:

1	September	2006	4	February	2008
29	November	2006	30	May	2008
1	February	2007	2	October	2008
29	May	2007	9	December	2008
17	September	2007	19	February	2009
3	December	2007	28	May	2009

Detailed minutes were recorded at all meetings. Early decisions were made concerning the content and funding of projects carried over from Stage 4 and of new projects started during Stage 5. 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. Of the two full-scale outdoor test-stands at Surahammar for braking experiments and noise measurements, the former 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 evaluations were carried out during Stages 4 and 5 but a new one is planned for Stage 6.

The NUTEK/VINNOVA ten-year funding of CHARMEC, totalling KSEK 52 925, ended on 30 June 2005. Additional contributions from Banverket and Chalmers University of Technology have 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. In addition, two separate applications from CHARMEC researchers to VINNOVA were approved and have resulted in three-year funding of the three railway mechanics projects TS11, VB10 and MU18 as reported in the following. An application to VR (The Swedish Research Council) resulted in three-year funding of project MU25. Family Ekman's Research Donation funds project SD6 for a period of five years.

Upon the initiative of CHARMEC's Board, a new round of written and oral interviews was conducted with Banverket and all individual members of the Industrial Interests Group during 2008* and summarized in a six-page document that was distributed between board members. Research needs were identified, that would also influence the Board's decisions regarding the start of new projects during Stage 6. Keywords that summarize the views expressed by Banverket and the eleven 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

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

The staff attached to the Centre during Stage 5, both at Chalmers (28 project leaders/principal advisers/senior researchers and 24 PhD students) and at Banverket and in the Industrial Interests Group (R&D management and experimental staff), have been actively involved. Numerous new contacts for co-operation have been established. Frequent meetings have taken place with university researchers and those working in industry, and these meetings have

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** A team of senior researchers from CHARMEC visited each one of Banverket and the eleven companies, staged a "Road Show" presenting CHARMEC and interviewed a group of specially summoned employees. Our Johan Ahlström (JA), Anders Ekberg (AE), Magnus Ekh (ME), Roger Lundén (RL), Jens Nielsen (JN) and Tore Vernersson (TV) took part. The visits were as follows during 2008:*

Green Cargo	Stockholm	7 March	JA+AE+JN	SweMaint	Göteborg	18 April	JA+AE+JN+TV
Bombardier	Västerås	14 March	JA+AE+JN	Abetong	Växjö	28 April	AE+JN
SL	Stockholm	14 March	JA+AE+JN	VAE	Zeltweg	17 June	ME+RL+JN
SJ	Stockholm	20 March	AE+RL+TV	voestalpine	Leoben	17 June	RL+JN
Lucchini	Surahammar	1 April	RL+TV	Faiveley	Landskrona	18 June	AE+TV
Interfleet	Stockholm	4 April	JA+AE+JN	Banverket	Borlänge	9 Sept	AE+RL+JN

led to both increased involvement in long-term industrial knowledge development and deeper insight into the working potential of the University. Mutual learning has been achieved. For more details concerning the specific results of business activities by CHARMEC's industrial partners, see each individual project.

Six Licentiate theses and seven PhD dissertations in railway mechanics were presented by CHARMEC's doctoral candidates during Stage 5, see page 80. In addition, 36 articles were published (or accepted for publication) in international scientific journals with a referee system, 58 papers were published in the proceedings of international conferences with a referee system, 9 EU reports were delivered, 19 research reports were edited in our own series of English-language research publications (without being internationally published), 4 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. For more information about these publications, see the lists under the projects described in the next section. One of our seven new PhDs during Stage 5 continued his work at the University, three have been employed by consultancies doing work in railway mechanics, and the remaining three are now employed in areas not related to railways.

As with Stages 1, 2, 3 and 4, four seminars are usually held during the morning of the day 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 Stage 4, members of the CHARMEC Board and people from Banverket 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 5 they were:

Håkan Fredriksson	SweMaint	1 February	2007
Sven Ödeen	Interfleet	29 May	2007
Rikard Bolmsvik	Abetong	17 September	2007
Bo Olsson	Banverket	3 December	2007
Helena Wetterwik	Green Cargo	4 February	2008
Hugo von Bahr	Interfleet	2 October	2008
Johan Oscarsson	SLTechnology	9 December	2008
Marcin Tubylewicz	Green Cargo	19 February	2009
Peter Linde	SweMaint/ Kockums Industrier	28 May	2009

Continued participation by CHARMEC researchers in EU projects (Sixth Framework Programme) has expanded our collaboration with companies, universities, institutes, public agencies and consultancies all over Europe. The CHARMEC network linked to EU projects during Stage 5 comprised some 100 organizations in 19 countries; see under projects EU9, EU10 and EU11. We also co-operate with railway bodies in Australia, Canada, 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 370 such articles and contributions have been published internationally so far. A total of 34 Licentiate degrees and 26 PhD degrees in railway mechanics have been awarded at Chalmers to date (June 2009), see again page 80.

CHARMEC runs no undergraduate or graduate courses in railway mechanics as such. However, a very positive consequence of CHARMEC's involvement in industrial problems has been the exposure and exploitation of several new areas of practical application in the traditional disciplines and courses at Chalmers (solid mechanics, structural mechanics, engineering metals, concrete structures, machine elements, manufacturing technology, control engineering, mechatronics, computer engineering, etc). This important impact on the regular courses raises the motivation of students. Several undergraduate students have been involved in project work and/or have written their MSc theses in railway mechanics. A graduate course in contact mechanics with wheel/rail applications was held during Stage 5, see page 90.

For special events and achievements during Stage 5, see page 88. 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 14 years of CHARMEC's Stages 1 to 5.

The publications listed under the projects have not previously been registered in CHARMEC's Biennial and Triennial Reports 1 July 1995 – 30 June 2006 (Stages 1, 2, 3 and 4), 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 5, 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 belong to the Sixth Framework Programme and can be found under EU's Priority 6 – Sustainable Development, Global Change and Ecosystems. 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. It should be noted that external access to EU documents supplied by us and others is often limited.

The departments where the 85 listed CHARMEC projects (TS1 – SP18) 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 103.

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 6, these only include the sums allocated by the Board up until the meeting on 28 May 2009.

The abbreviation Lic Eng stands for the intermediate academic degree *Licentiate of Engineering,* see page 80.

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 TrainTech Engineering (now Interfleet Technology) 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 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 has now left Interfleet Technology for a position at SL Technology in Stockholm. He has served on the Board of CHARMEC from November 2007.

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 24 and 29. For a new photo of Johan Oscarsson, see page 9

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 62

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

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 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 62

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.

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 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, Bombardier Transportation and Interfleet

TS5. (cont'd)

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

In October 2005, Anders Johansson left Chalmers for employment with consultancy Epsilon but was later contracted temporarily by CHARMEC to assist in projects TS10 and EU10. See also CHARMEC's Triennial Reports for Stages 2, 3 and 4. The article below was printed after the latter report was edited.

> Anders Johansson and Jens Nielsen: Rail corrugation growth – influence of powered wheelsets with wheel tread irregularities, *Wear*, vol 262, nos 11-12, 2007, pp 1296-1307

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

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

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 disk (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 launched 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 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

Project leader and supervisor	Professor Jens Nielsen, Applied Mechanics/ Division of Dynamics
Assistant supervisor	Professor Tore Dahlberg, Linköping Institute of Technology
Doctoral candidate	Mr Elias Kassa (from 2002-04-01; Lic Eng December 2004; PhD October 2007)
Period	2002-04-01–2007-08-31 and a prestudy 2001-06-01 – 2002-06-30
Chalmers budget (excluding university basic resources)	Stage 3: KSEK 500+750+500 KSEK 250 (VAE) Stage 4: KSEK 2050+100+300 +300+200 Stage 5: KSEK 600
Industrial interests in-kind budget	Stage 3: KSEK 200 *(Banverket)* Stage 4: KSEK 300+200+600 *(Banverket+SL Technology +voestalpine Bahnsysteme)* Stage 5: KSEK 200+50+600 *(Banverket+SL Technology +voestalpine Bahnsysteme)*

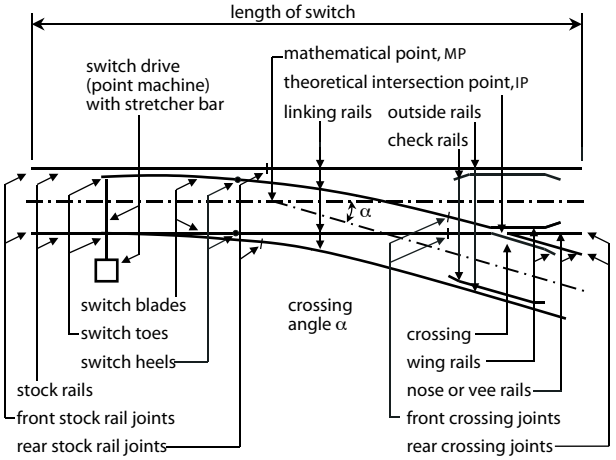
For photos of Jens Nielsen and Tore Dahlberg, see pages 17 and 62

The TS7 project was completed with Elias Kassa's successful defence in public of his doctoral dissertation in October 2007. The faculty-appointed external examiner of the dissertation was Dr Robert D Fröhling from Transnet in the Republic of South Africa. Data on the dissertation are presented below. During the period September 2006 – June 2008, Elias Kassa was initially employed part-time and later full-time by Banverket in Borlänge. He is now active at Manchester Metropolitan University in the UK.

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

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.

Two alternative multi-body system (MBS) models of dynamic interaction between the running train and a standard turnout design (UIC60-760-1:15) have been developed. The first model was derived using the commercial MBS software GENSYS. The second is based on the in-house software DIFF3D, see project TS4, with a detailed model of track dynamics and a multi-body dynamics formulation that accounts for excitation in an extended frequency range (up to several hundred Hz). Using an FE model, a complex-valued modal superposition of track dynamics was applied to account for the structural receptance of the track components. The 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, are considered. Hertzian theory and Kalker's algorithm FASTSIM were used for the normal and tangential wheel/rail rolling contact. Good agreement between the results from the two models was observed.



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"

Random distributions of the transverse wheel profile and a set of transverse rail profiles along the switch panel were accounted for by using the Karhunen-Loève expansion technique. There has been close co-operation with the CHARMEC partner VAE in Austria.

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

TS7. (cont'd)

in the field. Lateral and vertical wheel/rail contact forces were measured with an instrumented wheelset to validate the mathematical models. 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 has been quantified.

The joint reference group for projects TS7 and MU14 consisted of members from Abetong, Banverket, Luleå University of Technology, Storstockholms Lokaltrafik (SL), VAE and voestalpine Schienen. See also CHARMEC's Triennial Reports for Stages 3 and 4.

Elias Kassa and Göran Johansson: Simulation of train-turnout interaction and plastic deformation of rail profiles, *Vehicle System Dynamics,* vol 44, no 1, supplement 1, 2006, pp 349-359. Also presented at *19th IAVSD Symposium* in Milan (Italy) August – September 2005

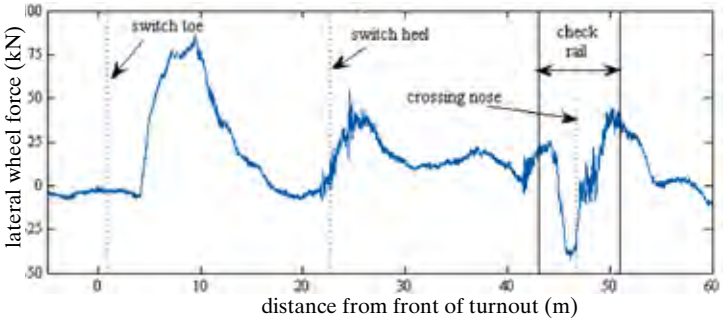
Elias Kassa: Dynamic train-turnout interaction – mathematical modelling, numerical simulation and field testing, Doctoral Dissertation, *Chalmers Applied Mechanics,* Gothenburg October 2007, 123 pp (introduction, summary and six appended papers)

Elias Kassa and Jens Nielsen: Dynamic interaction between train and railway turnout – full-scale field test and validation of simulation models, *Vehicle System Dynamics,* vol 46, nos 1-2, supplement 1, 2008, pp 521-534. Also presented at *20th IAVSD Symposium* in Berkeley CA (USA) August 2007 (also listed under project EU10)

Elias Kassa and Jens Nielsen: Stochastic analysis of dynamic interaction between train and railway turnout, *Vehicle System Dynamics,* vol 46, no 5, 2008, pp 429-449

Martina Wiest, Elias Kassa, Werner Daves, Jens Nielsen and Heinz Ossberger: Assessment of methods for calculating contact pressure in wheel-rail/switch contact, *Wear,* vol 265, nos 9-10, 2008, pp 1439-1445 (revised version of paper presented at conference *CM2006* in Brisbane (Australia) September 2006)

Elias Kassa and Jens Nielsen: Dynamic train-turnout interaction in an extended frequency range using a detailed model of track dynamics, *Journal of Sound and Vibration,* vol 320, nos 4-5, 2009, pp 893-914



Example of measured lateral contact force on outer leading wheel in turnout UIC60-760-1:15 at Härad on the Svealand Line in May 2006. Freight vehicle with axle load 25 tonnes and speed 80 km/h. Facing move in diverging route

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	2003-10-01–2009-06-30 (– 2012-06-30)
Chalmers budget (excluding university basic resources)	Stage 4: KSEK 1 500+700+350 Stage 5: KSEK 1 000 Stage 6: KSEK 200
Industrial interests in-kind budget	Stage 4: KSEK 400 *(Banverket)* Stage 5: KSEK 200+50 Stage 6: KSEK 100+50 *(Banverket+Abetong)*

For a photo of Jens Nielsen, see page 24

In this work, available software from CHARMEC projects for analysing dynamic train/track interaction, wear and rolling contact fatigue of wheel and rail, and ground vibrations and railway noise, is extended and integrated. Calculated high-frequency wheel/rail contact forces have been validated against forces measured by Interfleet Technology during the field tests 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 better to handle frequencies below 50 Hz. The overall aim of project TS8 is to develop a user-friendly computer tool for the rational design of the whole track and its individual components.

Wear models and creep routines from DIFF3D and from the parallel in-house 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. Work with improving the model for simulation of wheel/rail impact loads

TS8. (cont'd)

due to fresh wheel flats and insulated rail joints is ongoing. In this context, one or several contact models developed in project VB10 will be implemented in our computer code DIFF.

Jens Nielsen participated in the 4th International Conference on Railway Condition Monitoring in Derby (UK) on 18-20 June 2008. He was a member of the scientific committee for the 21st IAVSD Symposium on Dynamics of Vehicles on Roads and Tracks held in Stockholm on 17-21 August 2009. He was invited to write a chapter in the new Wheel/Rail Interface Handbook, see page 92.

Luis Baeza, Alejandro Roda and Jens Nielsen: Railway vehicle/track interaction analysis using a modal substructuring approach, *Journal of Sound and Vibration*, vol 293, nos 1-2, 2006, pp 112-124

Elena Kabo, Jens Nielsen and Anders Ekberg: Prediction of dynamic train/track interaction and subsequent material deterioration in the presence of insulated rail joints, *Vehicle System Dynamics,* vol 44, no 1, supplement 1, 2006, pp 718-729 (also listed under projects MU9 and SP8)

Anders Ekberg, Elena Kabo, Jens Nielsen and Roger Lundén: Subsurface initiated rolling contact fatigue of railway wheels as generated by rail corrugation, *International Journal of Solids and Structures,* vol 44, no 24, 2007, pp 7975-7987 (also listed under projects MU10 and SP11)

Jens Nielsen: High-frequency vertical wheel/rail contact forces – validation of a prediction model by field testing, *Wear,* vol 265, nos 9-10, 2008, pp 1465-1471 (revised article from conference *CM2006*. Also listed under project SP11)

Elias Kassa and Jens Nielsen: Stochastic analysis of dynamic interaction between train and railway turnout, *15th Nordic Seminar on Railway Technology,* Hook (Sweden) May 2008, 1+20 pp (Summary and PowerPoint presentation. Documented on CD)

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 (from 2004-02-09; Lic Eng November 2006)
Period	2004-01-01–2009-06-30 (to be prolonged)
Chalmers budget (excluding university basic resources)	Stage 4: kSEK 1 825+200 Stage 5: kSEK 1 925+230 Stage 6: –
Industrial interests in-kind budget (Abetong)	Stage 4: kSEK 300 Stage 5: kSEK 400 Stage 6: kSEK 100

For photos of Thomas Abrahamsson, Jens Nielsen and Johanna Lilja, see pages 17 and 21

Project TS9 focusses on the design loads for a sleeper installed in a track carrying different types of traffic. Important issues are the true statistical spread of the loads on the individual sleeper from the rails and the 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 is being used and a probabilistic design method for sleepers is being developed. The ultimate aim of the project is to develop guidelines for sleeper design that will also include recommendations for the design of the track as a whole.

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 cells over its bottom surface has been designed and manufactured. In-field measurements have taken place in September 2006 at Harrträsk (close to Gällivare) on the Iron Ore Line in Northern Sweden, and in September 2008 and June 2009 at Torpsbruk and Liatorp, respectively, on the Southern Main Line (close to Alvesta) where X2 trains and freight trains passed the studied site. 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 are being investigated: approximate reliability methods such as FORM and SORM, sampling methods that are variations of Latin Hypercube with Importance Sampling, and metamodelling with Monte Carlo Sampling. Appropriate optimization routines will be studied considering sleepers of different designs with a predefined allowed probability of failure.

The reference group for project TS9 includes members from Abetong, Banverket 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".

TS9. (cont'd)

Thomas Abrahamsson, Johanna Lilja and Jens Nielsen: Towards probabilistic design of railway sleepers, *15th Nordic Seminar on Railway Technology,* Hook (Sweden) May 2008, 1+14 pp (Summary and PowerPoint presentation. Documented on CD)

Johanna Lilja, Thomas Abrahamsson and Jens Nielsen: On the adequacy of metamodelling techniques in probabilistic design of railway sleepers, *Proceedings 4th International ASRANet Colloquium,* Athens (Greece) June 2008, 10 pp (documented on CD. *ASRANet* is a Network for Integrating Structural Analysis, Risk & Reliability)

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 are being 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
Co-worker	Dr Johan Jonsson, Vectura Consulting AB
Doctoral candidate	None (only senior researchers in this project)
Period	2005-06-01–2009-06-30 (to be prolonged)
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: –
Industrial interests in-kind budget (Abetong +Banverket)	Stage 4: KSEK 300+ 100 Stage 5: KSEK 150+150 Stage 6: KSEK 150+150

For photos of Rikard Bolmsvik, Jens Nielsen and Johan Jonsson, see pages 28 and 78

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 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). Rikard Bolmsvik has also represented Banverket in a UIC working group on USP.

Measurement campaigns, before and after installation of USP, have been run at Furet (close to Halmstad on the

Under Sleeper Pads (courtesy Getzner Werkstoffe GmbH)

TS10. (cont'd)

Swedish West Coast Line) in October-November 2005 and October-November 2006, respectively, and on the SBB test track at Kiesen (close to Bern) in Switzerland in May-June 2007. In both cases track properties were measured by use of Banverkets RSMV (Rolling Stiffness Measurement Vehicle). Accelerations and strains of rails and sleepers were registered during train passages. At Kiesen also SBB's EMW (EinsenkungsMessWagen) was used.

The results from the measurements at Kiesen agree with the results of a numerical parameter study: (i) a low USP stiffness decreases the loading on each sleeper but will increase the vertical acceleration of the sleepers, and (ii) a high USP stiffness leads to sleeper responses similar to those obtained for sleepers without USP. Track settlement appears to be slowed down when the USP have a low stiffness implying that track quality is being maintained more effectively. Network Rail in the UK has taken an interest in project TS10.

A final report on project TS10 will be delivered by Rikard Bolmsvik. Project TS10 had an informal reference group with representatives from Banverket, Christian Berner AB, Getzner Werkstoffe GmbH and SBB Infrastruktur.

Jens Nielsen: Oral presentation of TS10 results at the symposium *Erfahrungen mit besohlten Schwellen und Lösungen für Weichen* arranged by Getzner Werkstoffe in Schwarzenberg (Austria) on 14-16 November 2007 (documented on CD)

Anders Johansson, Jens Nielsen, Rikard Bolmsvik, Anders Karlström and Roger Lundén: Under sleeper pads – influence on dynamic train/track interaction, *Wear,* vol 265, nos 9-10, 2008, pp 1479-1487 (revised article from conference *CM2006*)

Johan Jonsson, Philippe Schneider, Rikard Bolmsvik, Tony Johansson and Jens Nielsen: Experimental study of the influence of USP on track response using LSQ on field measurement data, *15th Nordic Seminar on Railway Technology*, Hook (Sweden) May 2008, 1+18 pp (Summary and PowerPoint presentation. Documented on CD)

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, MSc (from 2007-02-26)
Period	2005-06-01–2009-06-30 (–2012-01-31)
Chalmers budget (excluding university basic resources)	Stage 4: KSEK 125 Stage 5: KSEK 2050 Stage 6: KSEK 2400
Industrial interests in-kind budget	Stage 4: – Stage 5: KSEK 200+50+200 Stage 6: KSEK 200+50+200 *(Banverket+SL Technology +voestalpine Bahnsysteme)*

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

For photos of Jens Nielsen, Anders Frid and Peter Torstensson, see pages 25 and 79

SL metro train of type C20 on a curve at Stora Mossen in Stockholm

TS11. (cont'd)

The in-house simulation program DIFF3D, see project TS4, is being employed to further develop a model of 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 bogie 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 are being used to validate both the growth rate of the corrugation and its variation along the curve. Remedies to reduce corrugation growth, such as wheel/rail friction modifiers and modifications in wheelset and bogie design, will be investigated. The present project is being run in co-operation with project VB10. A foundation is thus being laid for the prediction of rolling noise emission from a train negotiating a curve.

CAT (Corrugation Analysis Trolley) measurements of rail corrugation on a 120 m radius curve between Alvik and Stora Mossen on SL's network in Stockholm have been performed. The measurement campaign also included train speed, 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 been built up on the low (inner) rail of the SL curve with maximum peak-to-peak magnitudes of about 0.15 mm. The corrugation pattern had a pure longitudinal direction and an irregularly varying magnitude along the 100 m long measured track section. The roughness growth rate increased with time until about 300 days after rail grinding. Thereafter, a more moderate growth was observed.

Computer models of the track at the test site and of a C20 bogie have been built using DIFF3D, see project TS4. Simulation results of dynamic vehicle/track interaction from DIFF3D have been validated against results obtained by use of the commercial computer program GENSYS. A good matching was found.

A collaboration between the projects TS11 and MU20 has been initiated. A computer model representing the conditions in the wear test rig of voestalpine in Leoben (Austria) has been established. One aim is to calibrate a wear model for the voestalpine 350HT rails used by SL.

The joint reference group for projects TS11 and VB10 consists of members from Banverket and SL Technology and from Bombardier Transportation in Siegen (Germany), Sweden and Switzerland.

Rail corrugation on a curve of SL track at Stora Mossen in Stockholm. Photo taken in October 2008

Peter Torstensson: Rail corrugation growth on curves, *15th Nordic Seminar on Railway Technology,* Hook (Sweden) May 2008, 1+34 pp (Summary and PowerPoint presentation. Documented on CD)

Peter Torstensson and Jens Nielsen: Monitoring of rail corrugation growth due to irregular wear on a railway metro curve, *Wear*, vol 267, part 1, 2009, pp 556-561. Also presented at *17th International Conference on Wear of Materials (WOM2009)* in Las Vegas NV (USA) April 2009

Peter Torstensson and Jens Nielsen: Simulation of dynamic train-track interaction on small radius curves subjected to rail corrugation, *Poster at 21st IAVSD Symposium on Roads and Tracks (IAVSD 2009),* Stockholm (Sweden) August 2009

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, *Proceedings 8th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2009),* Florence (Italy) September 2009, vol 2, pp 701-710 (also listed under project MU20)

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, Applied Mechanics / Division of Material and Computational Mechanics
Assistant supervisors	Dr Peter Möller, Professor Jens Nielsen and Professor Kenneth Runesson, Applied Mechanics
Doctoral candidate	Mr Hamed Ronasi, MSc (from 2007-09-01)
Period	2007-09-01–2009-06-30 (–2012-08-31)
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)*

Project TS12 aims to identify forces arising in train and track during railway traffic, in particular those in the wheel/rail contact which are difficult to measure with direct methods. The strategy launched in project TS6 is being further developed. Key tasks are to (i) assess an existing all-experiment based identification method (developed by the CHARMEC partner Interfleet Technology) by using new calculations together with existing measurement results, (ii) study the effects of modelling and regularization on the estimated forces, and (iii) suggest new experimental set-ups for an accurate evaluation of the wheel/rail contact forces, not only in the vertical direction but also in the lateral and longitudinal directions.

In a preliminary study, a two-dimensional (2D) circular disk has been taken as a representative of a train wheel. By introducing the proper gyroscopic-type and centrifugal terms in the equations of motion, the disk can be considered as fixed, while a radial concentrated force travels around the disk's perimeter (representing the contact force acting on the rim of the wheel), see figure. Via a numerical solution of the equations of motion, the predicted radial strains are extracted at a set of points corresponding to strain gauge positions. Important issues are the choice of sampling instances for the measurements, parameterization of the sought input and the discretization of the pertinent state equations in an FE setting. In contrast to traditional methods, e g, dynamic programming, all these discretizations are decoupled. This is critical in order to enable a control of discretization errors, noise sensitivity and ill-posedness of the identification problem.

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

Hamed Ronasi: Identification of wheel-rail contact forces, *15th Nordic Seminar on Railway Technology,* Hook (Sweden) May 2008, 1+20 pp (Summary and PowerPoint presentation. Documented on CD)

Hamed Ronasi, Håkan Johansson and Fredrik Larsson: A numerical framework for load identification with application to wheel-rail contact forces, *Proceedings ECCOMAS International Symposium on Inverse Problems in Mechanics of Structures and Materials (IPM2009),* Rzeszów Łańcut (Poland) April 2009, pp 69-70 (ECCOMAS stands for European Community on Computational Methods in Applied Sciences)

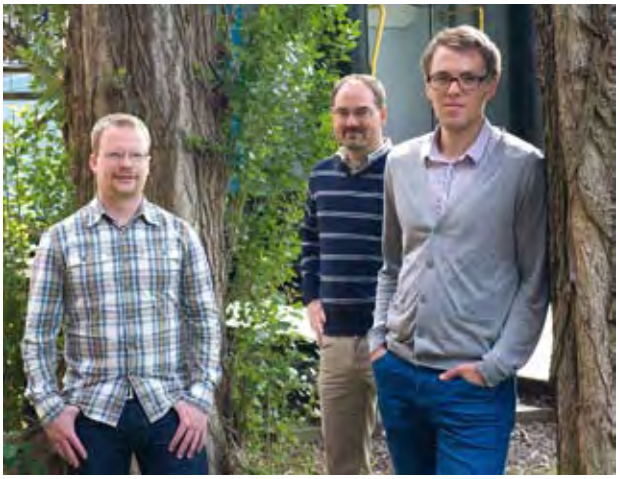
PhD student Hamed Ronasi (right) and his supervisors Docent Fredrik Larsson (left), Dr Håkan Johansson (second from the left) and Professor Jens Nielsen. For photos of Dr Peter Möller and Professor Kenneth Runesson see pages 17 and 44

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, MSc (from 2008-09-01)
Period	2008-09-01–2009-06-30 (–2013-08-31)
Chalmers budget (excluding university basic resources)	Stage 5: KSEK 650 Stage 6: KSEK 2 550
Industrial interests in-kind budget	Stage 5: KSEK 200 *(voestalpine)* Stage 6: KSEK 200+50+200 *(Banverket + SL Technology + voestalpine Bahnsysteme)*

In this project, a numerical method will be developed for the optimal design of track switches (turnouts) aiming at a reduction of dynamic wheel/rail contact forces and subsequent switch component degradation. Examples of design variables to be used in the optimization are rail profile, rail inclination, stiffness of resilient layers (e g, rail pads and under sleeper pads), and nominal track gauge variation in the switch panel. In particular, the method will account for the stochastic distribution (scatter) of load parameters such as worn wheel profiles and varying train speed, axle load and wheel/rail friction. Models for simulation of dynamic interaction between train and switch, as developed in the previous CHARMEC project TS7, will be employed. The optimization will be based on a so-called robust design methodology. A target design could be an optimum combination of a variation of switch rail profile and a nominal variation of track gauge, which would lead to reduced contact stresses (improved performance) on the switch rail despite a traffic load with large variations in worn wheel profiles. Recommendations on track switch design (geometry, material and stiffness) to reduce maintenance costs will be given. The present project is being run in co-operation with project EU10.

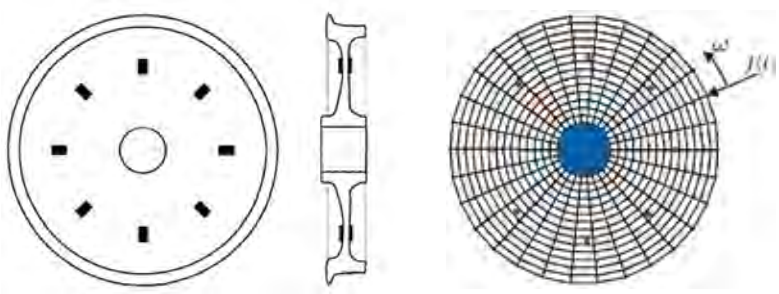


PhD student Peter Torstensson of project TS11 (right), PhD student Björn Pålsson of project TS13 (left) and their supervisor Professor Jens Nielsen. For a photo of Professor Thomas Abrahamsson, see page 21

The project has started with a literature study on stochastic modelling, an introduction to modelling and simulation in the commercial code GENSYS, and a statistical assessment of wheel/rail contact loads and contact positions on a crossing based on calculations performed by Deutsche Bahn in the INNOTRACK project, see EU10. The research plan for project TS13 is dated 2008-08-29. The reference group for project TS13 has members from Banverket, SL Technology and VAE. A first meeting with VAE was held in Gothenburg in December 2008 and a second in Zeltweg (Austria) in June 2009.

Dirk Nicklisch, Jens Nielsen, Magnus Ekh, Anders Johansson, Björn Pålsson, Jörg Reinecke and Andreas Zoll: Simulation of wheel–rail contact forces and subsequent material degradation in switches & crossings, *Proceedings 21st IAVSD Symposium on Dynamics of Vehicles on Roads and Tracks,* Stockholm (Sweden) August 2009, 14 pp (documented on CD)

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, *Proceedings 8th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems* (*CM2009*), Florence (Italy) September 2009, vol 3, pp 987-996



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)

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 28

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.

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 disk-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 57, 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

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 17 and 27

then left Chalmers for employment elsewhere. The title of his licentiate thesis is "Noise-related roughness of railway wheels – testing of thermomechanical interaction between brake block and wheel tread".

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 56.

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.

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 project VB10 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 79

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 of 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 is partly a continuation of VB5. See also CHARMEC's Triennial Reports for Stages 2, 3 and 4. The following article has been published since the last reports was edited.

Torbjörn Ekevid, Per Kettil, Håkan Lane and Nils-Erik Wiberg: Computational railway dynamics, *Proceedings 3rd European Conference on Computational Solid and Structural Mechanics (CSSM 2006),* Lisbon (Portugal) June 2006, pp 577-598 (documented on CD)

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 has 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

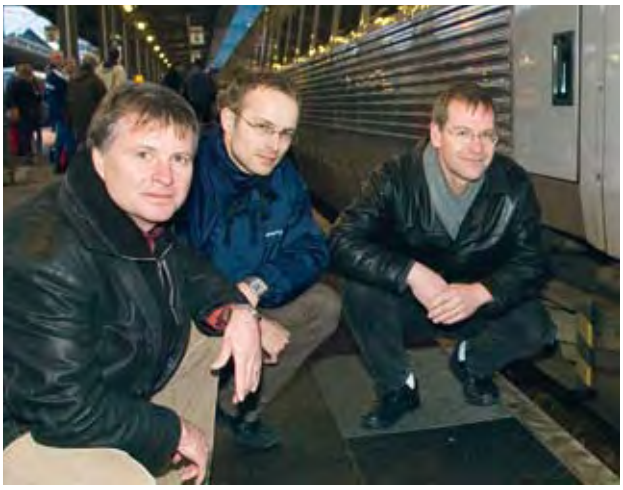
Project leaders and supervisors	Professor Thomas Abrahamsson, Applied Mechanics/ Division of Dynamics, and Professor Tomas McKelvey, Signals and Systems
Doctoral candidate	Mr Per Sjövall (formerly Per Kalling) (from 2003-03-01; Lic Eng October 2004; PhD November 2007)
Period	2001-07-01 – 2008-02-29
Chalmers budget (excluding university basic resources)	Stage 3: KSEK 704 Stage 4: KSEK 2 050 Stage 5: KSEK 704
Industrial interests in-kind budget (Bombardier Transportation)	Stage 3: KSEK 300 Stage 4: KSEK 200 Stage 5: KSEK 100

Project VB7 was completed with Per Sjövall's successful defence in public of his doctoral dissertation in November 2007. 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. Data on the dissertation are presented below.

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 has been 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.

The reference group for project VB7 consisted of members from Banverket, Bombardier Transportation, Interfleet Technology and KTH Railway Group.



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

Per Sjövall: Identification and synthesis of components for vibration transfer path analysis, Doctoral Dissertation, *Chalmers Applied Mechanics,* Gothenburg November 2007, 149 pp (introduction, summary and five appended papers)

Per Sjövall and Thomas Abrahamsson: Component system identification and state-space model synthesis, *Mechanical Systems and Signal Processing*, vol 21, no 7, 2007, pp 2697-2714

Per Sjövall and Thomas Abrahamsson: Substructure system identification from coupled system test data, *ibidem,* vol 22, no 1, 2008, pp 15-33

Per Sjövall and Thomas Abrahamsson: Transmission path characterization for passive vibration control, *Proceedings 14th International Congress on Sound and Vibration (ICSV14)*, Cairns (Australia) July 2007, 8 pp (documented on CD)

Per Sjövall and Thomas Abrahamsson: State-space model identification for component synthesis, *Proceedings 25th International Modal Analysis Conference (IMAC XXV)*, Orlando FL (USA) February 2007, pp 120-132 (documented on CD)

Per Sjövall, Thomas Abrahamsson and Tomas McKelvey: Optimal sensor placement for indirect vibration sensing (submitted to *Mechanical Systems and Signal Processing)*

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 from 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 29

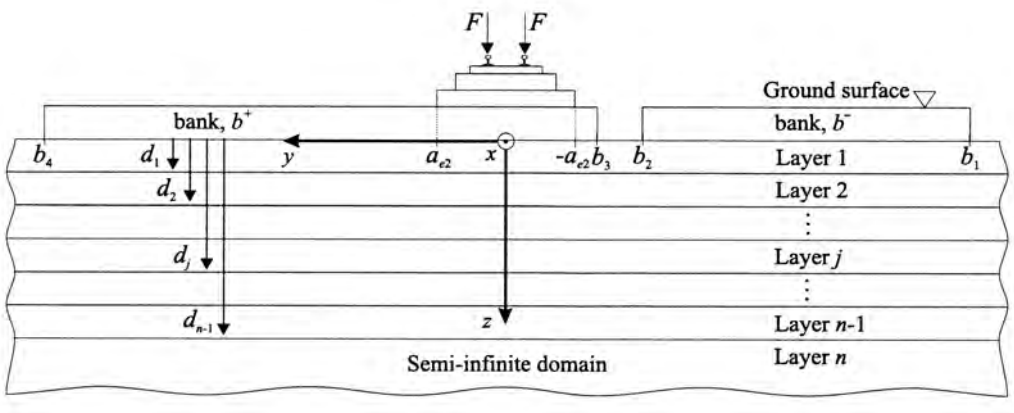
Project VB8 was completed with Anders Karlström's successful defence in public of his doctoral dissertation in October 2006. Professor Anders Boström and Professor Thomas Abrahamsson from Chalmers Applied Mechanics were his supervisors. The faculty-appointed external examiner of the dissertation was 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 article below was finished after the report was edited. The present analytical model has been integrated with the numerical time-domain model in DIFF3D, see project TS8.

The reference group of project VB8 consisted of representatives from Banverket, KTH Soil and Rock Mechanics and Norwegian Geotechnical Institute (NGI).

Anders Karlström and Anders Boström: Efficiency of trenches along railways for trains moving at sub- or supersonic speeds, *Soil Dynamics and Earthquake Engineering*, vol 27, no 7, 2007, pp 625-641



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

Project leaders and supervisors	Professor Nils-Erik Wiberg, Applied Mechanics/ Division of Material and Computational Mechanics, and Dr Torbjörn Ekevid, Växjö University
Doctoral candidate	Mr Håkan Lane (from 2002-06-01 in his department; from 2004-07-01 in the CHARMEC project; Lic Eng June 2005; PhD May 2007)
Period	2004-07-01 – 2007-06-30
Chalmers budget (excluding university basic resources)	Stage 4: kSEK 1 800 Stage 5: kSEK 900
Industrial interests in-kind budget	Stage 4: – Stage 5: –

For a photo of Nils-Erik Wiberg and Torbjörn Ekevid, see page 28

The VB9 project was completed with Håkan Lane's successful defence in public of his doctoral dissertation (see below) in May 2007, when he also left Chalmers. 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 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 have been 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.

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 Report for Stage 4.

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

Håkan Lane, Sebastian Berg and Martin Larsson: Finite element calculations of rail vibration countermeasures, *Vehicle System Dynamics,* vol 45, no 6, 2007, pp 565-581 (revised article from conference *MMWP05*)

Håkan Lane, Torbjörn Ekevid, Per Kettil, Chuan-Yuen Ching and Nils-Erik Wiberg: Vehicle-track-underground modeling of rail induced wave propagation, *Computers and Structures,* vol 85, nos 15-16, 2007, pp 1215-1229

Håkan Lane, Per Kettil and Nils-Erik Wiberg: Moving finite elements and dynamic vehicle interaction, *European Journal of Mechanics – A/Solids,* vol 27, no 4, 2008, pp 515-531

Håkan Lane: Computational railway dynamics – integrated track-train-subgrade modeling and simulation, Doctoral Dissertation, *Chalmers Applied Mechanics,* Gothenburg May 2007, 189 pp (introduction, summary and seven appended papers)

Håkan Lane, Chuan-Yuen Ching and Nils-Erik Wiberg: Adaptive strategies for improved ride comfort over imperfect tracks, *Proceedings 3rd International Conference on Adaptive Modeling and Simulation (ADMOS 2007* / an ECCOMAS Thematic Conference), Gothenburg October 2007, pp 138-141

Håkan Lane, Per Kettil and Nils-Erik Wiberg: Rail vibrations caused by ground stiffness transitions, Keynote Lecture delivered by Nils-Erik Wiberg at the conference *Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN2007* / an ECCOMAS Thematic Conference), Rethymno/ Crete (Greece) June 2007. Printed in *Computational Structural Dynamics and Earthquake Engineering,* Taylor & Francis, London (UK) 2009, pp 179-188

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)
Period	2006-05-01 – 2009-06-30 (– 2011-04-30)
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 is partially financed by VINNOVA (through CHARMEC's budget)

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. On the one hand, rolling noise and impact noise is caused by the vertical interaction excited by roughness and discrete irregularities on the wheel and rail running surfaces. On the other hand, squeal noise, predominantly occurring on curves, is generated by the tangential interaction. While a well-established frequency-domain model is available for the prediction of rolling noise, likewise successful models do not yet exist for the prediction of impact and squeal noise. The overall aim of project VB10 is to develop suitable models for wheel/rail interaction and the ensuing noise generation. Project VB10 takes place in close co-operation with project TS11.

Vertical interaction models have been formulated in the time domain allowing the inclusion of non-linearities in the contact zone. Linear models of wheel and track are represented by Green's functions, which leads to a computationally efficient formulation. A first contact model is two-dimensional (2D) and consists of a bedding of independent springs. Only one line of wheel/rail roughness in the rolling direction is taken into account here. A second contact model is three-dimensional (3D) and is based on an influence-function method for an elastic half-space. The real three-dimensional wheel and rail geometry is considered with the roughness along several parallel lines being included.

These two models have been applied to evaluate the contact filter effect, which consists in the attenuation of high-frequency excitation at the wheel/rail contact. The results show that the application of the 3D contact model is preferable when the degree of correlation between roughness profiles across the width of the contact is low. The interaction model using the 2D contact model has been applied to simulate impact forces caused by wheel flats and the results show encouraging agreement with field measurements.

Astrid Pieringer presented her licentiate thesis (see below) at a seminar on 2008-12-02 where the discussion was introduced by Dr Franck Poisson of SNCF. From February 2009, Astrid Pieringer visited ISVR (Institute of Sound and Vibration Research) in Southampton (UK) for six months where she worked with Professor David J Thompson on the modelling of vertical and tangential wheel/rail interaction. Earlier visits have been paid to research groups in Paris (Pierre-Etienne Gautier of SNCF) and Milan (Stefano Bruni of Politecnico di Milano). On 18-19 April 2009, Chalmers Applied Acoustics participated in an SNCF measurement campaign on rolling and impact noise.

The joint reference group for projects TS11 and VB10 consists of members from Banverket and SL Technology and from Bombardier Transportation in Siegen (Germany), Sweden and Switzerland.

PhD student Astrid Pieringer (licentiate gained in December 2008) and her supervisor Professor Wolfgang Kropp in project VB10. Photo taken in the laboratory of Chalmers Applied Acoustics. A scale model of a Regina train compartment, as seen in the bench, is used in a master's project for Bombardier Transportation Sweden on sound propagation

VB10. (cont'd)

Astrid Pieringer, Wolfgang Kropp and Jens Nielsen: A time domain model for wheel/rail interaction aiming to include non-linear contact stiffness and tangential friction, presented at *9th International Workshop on Railway Noise* (IWRN9) in Feldafing/Munich (Germany) September 2007. With an abbreviated version in *Notes on Numerical Fluid Mechanics and Multidisciplinary Design,* vol 99 (Noise and Vibration Mitigation for Rail Transportation Systems), Springer, Berlin 2008, pp 285-291

Astrid Pieringer and Wolfgang Kropp: Simulation of impact forces caused by wheel flats – a parameter study, *15th Nordic Seminar on Railway Technology*, Hook (Sweden) May 2008, 1+36 pp (Summary and PowerPoint presentation. Documented on CD)

Astrid Pieringer and Wolfgang Kropp: A fast time-domain model for wheel/rail interaction demonstrated for the case of impact forces caused by wheel flats, *Proceedings 2nd ASA-EAA Joint Conference Acoustics'08,* Paris (France) June-July 2008, 6 pp (documented on CD). Abstract in *Journal of the Acoustical Society of America (JASA),* vol 123, no 5, p 3266

Astrid Pieringer: Modelling of wheel/rail interaction considering roughness and discrete irregularities, Licentiate Thesis, *Chalmers Applied Acoustics,* Gothenburg December 2008, 88 pp (introduction, extended summary and two 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, *Proceedings 8th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2009)*, Florence (Italy) September 2009, vol 1, pp 105-113

MU1. MECHANICAL PROPERTIES OF BALLAST

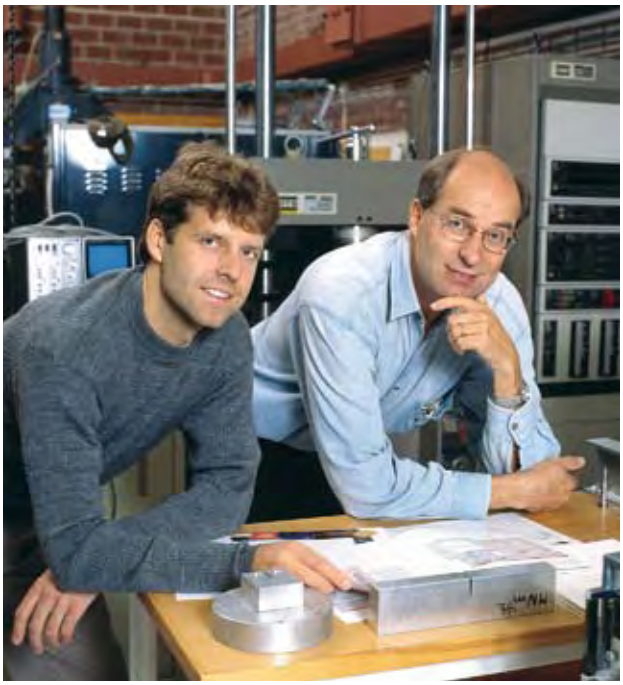
Ballastens mekaniska egenskaper
Mechanische Eigenschaften des Schotters
Propriétés mécaniques du ballast

Project leader and supervisor	Professor Kenneth Runesson, Solid Mechanics (later Structural Engineering and Mechanics, now Applied Mechanics)
Doctoral candidate	Mr Lars Jacobsson (from 1996-04-01; Lic Eng January 1999)

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.

Work on the MU1 project has been delayed. Lars Jacobsson has 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. The title of the licentiate thesis is "A plasticity model for cohesionless material with emphasis on railway ballast". See also CHARMEC's Biennial and Triennial Reports for Stages 1, 2 and 3.



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

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.

For a photo of Johan Ahlström and Birger Karlsson, see page 51.

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 27

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 multiaxial 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 and MU22 with continued research in the same area.

Anders Ekberg has been employed as senior researcher at Chalmers Solid Mechanics (now Applied Mechaics) since April 2000, where he has worked in close co-opeation with Dr (now Docent) Elena Kabo. In parallel with project MU22, he is now also involved in projects MU18, MU21, MU25, EU9, EU10, SP7, SP11, SP13 and SP14. In August 2005, Anders Ekberg was appointed Docent, see page 80.

For a photo of Anders Ekberg and Roger Lundén, see page 50.

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. Since December 2002, Rikard Bolmsvik has been employed by Abetong AB in Växjö, Sweden. He is now involved in projects TS10, SP9, SP12, SP16 and SP17 and also serves on the Board of CHARMEC from July 2008, see pages 8 and 9.

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 9

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 80. 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 45

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 Luleå and Umeå, Sweden.

MU7. (cont'd)

Simon Niederhauser, Birger Karlsson and Peter Sotkovszki: Microstructural study of a Co-Cr laser clad (included in Simon Niederhauser's dissertation)

Simon Niederhauser, Birger Karlsson and Peter Sotkovszki: Microstructure and fatigue properties of a Fe-12.5% Cr laser cladded steel plate (included in Simon Niederhauser's dissertation)

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

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 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 45. For a photo of Jonas Ringsberg, see page 39

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 39) 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 article below has been printed since the latter report was edited. The joint reference group for projects MU9 and MU10 included representatives from Bombardier Transportation Sweden and Interfleet Technology.

Elena Kabo, Jens Nielsen and Anders Ekberg: Prediction of dynamic train/track interaction and subsequent material deterioration in the presence of insulated rail joints, *Vehicle System Dynamics,* vol 44, no 1, supplement 1, 2006, pp 718-729 (also listed under projects TS8 and SP8)

Robert Fröhling, Anders Ekberg and Elena Kabo: The detrimental effects of hollow wear – field experiences and numerical simulations, *Wear,* vol 265, nos 9-10, 2008, pp 1273-1291 (revised article from conference *CM2006*)

MU10. CRACK PROPAGATION IN RAILWAY WHEELS

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

Project leaders and supervisors	Professor Hans Andersson, Dr (now Docent) Elena Kabo and Docent Anders Ekberg, Applied Mechanics/Division of Material and Computational Mechanics
Doctoral candidate	Ms Eka Lansler (from 2002-02-01 to 2005-03-31; Lic Eng January 2005)
Period	2002-02-01–2007-06-30
Chalmers budget (excluding university basic resources)	Stage 3: KSEK 1100 Stage 4: KSEK 2050 Stage 5: KSEK 271
Industrial interests in-kind budget (Lucchini Sweden)	Stage 3: KSEK 400 Stage 4: KSEK 100 Stage 5: KSEK 100

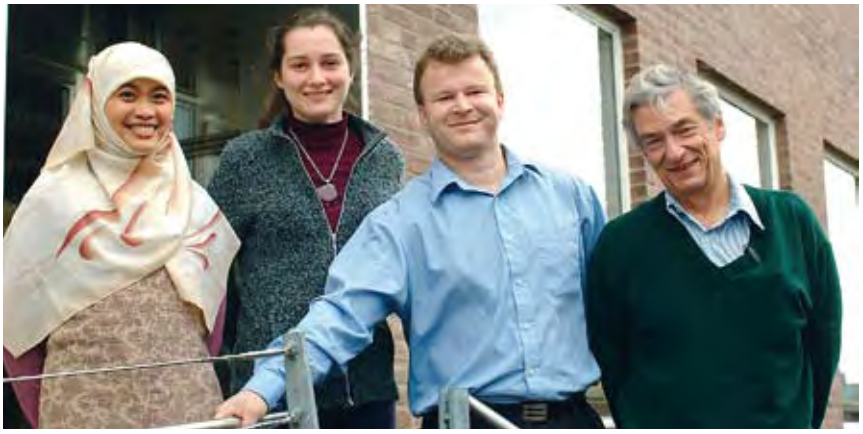
Eka Lanser left Chalmers after gaining her licentiate degree, and a revised research plan was adopted. The title of Eka Lansler's thesis is "Subsurface rolling contact fatigue cracks in railway wheels – elastoplastic deformations and mechanisms of propagation". The discussion at the licentiate seminar 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. The articles below have been printed since the latter report was edited.

MU10. (cont'd)



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

Eka Lansler, Anders Ekberg, Elena Kabo and Hans Andersson: Influence of plastic deformations on growth of subsurface rolling contact fatigue cracks in railway wheels, *IMechE Journal of Rail and Rapid Transit*, vol 220, no F4, 2006, pp 461-473

Andrea Gianni, Tord Karlsson, Andrea Ghidini and Anders Ekberg: Bainitic steel grade for solid wheels: metallurgical, mechanical and in-service testing, *Proceedings International Heavy Haul Association Specialist Technical Session (IHHA STS 2007),* Kiruna (Sweden) June 2007, pp 701-711 (this work received an Award Best Paper)

Roger Lundén: Elastoplastic modelling of subsurface crack growth in rail/wheel contact problems, *Fatigue & Fracture of Engineering Materials & Structures,* vol 30, no 10, 2007, pp 905-914

Anders Ekberg, Elena Kabo, Jens Nielsen and Roger Lundén: Subsurface initiated rolling contact fatigue of railway wheels as generated by rail corrugation, *International Journal of Solids and Structures,* vol 44, no 24, 2007, pp 7975-7987 (also listed under projects TS8 and SP11)

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 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 44 and 45

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

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.

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

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 Johan Ahlström and Professor Birger Karlsson from Chalmers Materials and Manufacturing Technology (for photo, see page 51). 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. The article below was finished after the latter report was edited.

Johan Ahlström and Birger Karlsson: Modified railway steels – production and evaluation of mechanical properties with emphasis on low cycle fatigue behaviour, *Metallurgical and Materials Transactions A*, vol 40, no 7, 2009, pp 1557-1567

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

MU14. DAMAGE IN TRACK SWITCHES

Skador i spårväxlar
Schäden an Weichen
Détérioration des aiguillages

Project leaders and supervisors	Docent Magnus Ekh, Senior Lecturer, and Professor Kenneth Runesson, Applied Mechanics/Division of Material and Computational Mechanics
Doctoral candidate	Mr Göran Johansson (from 2002-08-01; Lic Eng June 2004; PhD September 2006)
Period	2002-08-01–2008-06-30
Chalmers budget (excluding university basic resources)	Stage 3: KSEK 500 KSEK 300 *(voestalpine Bahnsysteme)* Stage 4: KSEK 2 150+100 Stage 5: KSEK 500
Industrial interests in kind budget	Stage 3: – Stage 4: KSEK 300+100+400 *(Banverket+SL Technology + voestalpine Bahnsysteme)* Stage 5: KSEK 100 *(voestalpine Bahnsysteme)*

The first part of this project 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 multiaxial 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.

Göran Johansson and Magnus Ekh: Modeling of large ratcheting strains with large time increments, *Engineering Computations*, vol 24, no 3, 2007, pp 221-236

Göran Johansson: On the non-oscillation criterion for multiplicative anisotropic plasticity at large simple shear deformation, *International Journal of Plasticity,* vol 24, no 7, 2008, pp 1190-1204

Göran Johansson: ABAQUS-UMAT implementation of a large strain hyper-elastoplastic model with kinematic hardening, Research Report 2008:01, *Chalmers Applied Mechanics*, Gothenburg 2008, 11 pp

Dr Göran Johansson (centre; doctorate earned in September 2006) and his supervisors Docent 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 Johan Ahlström from Chalmers Materials and Manufacturing Technology (for photo, see page 51). 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	Dr Johan Ahlström, Senior Lecturer, and Professor Birger Karlsson, Materials and Manufacturing Technology
Doctoral candidate	Mr Niklas Köppen (from 2003-10-01 to 2006-11-30; Lic Eng November 2006)
Period	2003-03-01–2009-06-30
Chalmers budget (excluding university basic resources)	Stage 3: KSEK 50 Stage 4: KSEK 2 000 Stage 5: KSEK 1 300
Industrial interests in-kind budget	Stage 3: – Stage 4: KSEK 100+500 *(Bombardier Transportation +Lucchini Sweden)* Stage 5: KSEK 400 *(voestalpine Bahnsysteme)*

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 and internal or external defects etc. This calls for more damage-tolerant base materials. The aim of project MU16 has been to study and develop alternative materials.

As described in detail in the CHARMEC Triennial Report for Stage 4, investigations have been performed on a batch of wheels with material specification UIC R8T delivered by Lucchini Sidermeccanica in Italy. A general observation of practical importance from our testing was that flow stress levels are increased when the temperature is decreased or when the strain rate is increased. Since the material reactions are identical, higher strain rates occurring in service can be simulated by decreasing the temperature in labora-

MU16. (cont'd)

tory tests. An increased strain rate by a factor of 100 can thus be simulated through a decrease in temperature of about 10°C.

Since the beginning of 2007, the present project has been reoriented towards studies on the fatigue properties of high-manganese steels and martensitic steel grades (as used in crossings and switches) in collaboration with VAE in Zeltweg, Austria. Three different materials are examined in tensile and push-pull low-cycle fatigue tests: as-cast Mn13 steel, Mn13 steel that has been exposed to explosive deformation hardening (EDH), and a martensitic steel, 51CrV4, cast and heat treated. The austenitic Mn13 steel was found to harden strongly and to be very forgiving due to its high ductility. Because of porosity it becomes sensitive to tensile stresses in cyclic straining (crack initiation at pores due to stress concentration). During revenue railway service, however, high hydrostatic stresses make the steel survive despite the pores existing after casting. The martensitic 51CrV4 steel is very hard and it is free from large defects. It softens during cyclic deformation, but remains harder throughout the fatigue life than 900A steel, for example, which was examined in the previous MU13 project.

After the doctoral candidate's resignation in November 2006, the project has been run by the senior researchers and 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 a later phase of project MU16. See also CHARMEC's Triennial Reports for Stages 3 and 4.

The title of Niklas Köppen´s licentiate thesis is "Deformation behaviour of near fully pearlitic railway steels during monotonic and cyclic loading". At the licentiate seminar in November 2006, Professor Jens Bergström from Materials Engineering at Karlstad University (Sweden) introduced the discussion.

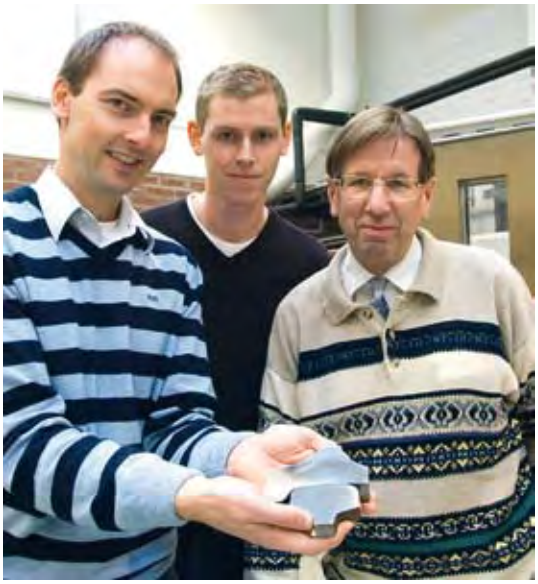
Peter Krahl: Fatigue properties of a martensitic steel for use in highly stressed railway components, MSc Thesis 100/2007, *Chalmers Materials and Manufacturing Technology*, Gothenburg 2007, 43 pp

Samuel Österberg: Fatigue properties of an austenitic Mn-steel for use in highly stressed railway components, MSc Thesis 101/2007, *ibidem*, Gothenburg 2007, 34 pp

Magnus Hörnqvist, Birger Karlsson and Johan Ahlström: Unloading stiffness of near fully pearlitic steel UIC-R8/R8T during cyclic plastic straining, *Proceedings 6th International Conference on Low Cycle Fatigue* (*LCF6*), Berlin (Germany) September 2008, pp 487-492

Johan Ahlström and Birger Karlsson: Low cycle fatigue behaviour of alternative steels for highly stressed railway components, *ibidem,* pp 747-752

Johan Ahlström and Birger Karlsson: Stiffness changes during fatigue of railway steels R8/R8T at ambient and subzero temperatures, *Proceedings 8th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2009)*, Florence (Italy) September 2009, vol 1, pp 7-9



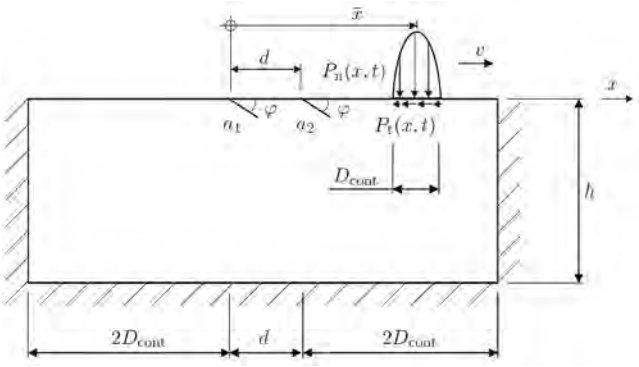
PhD student Niklas Köppen (centre; licentiate gained in November 2006) and his supervisors Dr Johan Ahlström (left) and Professor Birger Karlsson in project MU16. Photo taken in 2006

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)
Period	2005-12-01 – 2009-06-30 (–2010-11-30)
Chalmers budget (excluding university basic resources)	Stage 4: KSEK 500 Stage 5: KSEK 2 350 Stage 6: KSEK 2 050
Industrial interests in-kind budget	Stage 4: KSEK 200 Stage 5: KSEK 300 Stage 6: KSEK 300 *(voestalpine Bahnsysteme)*

Project MU17 deals with the numerical simulation of crack propagation in rails in the context of rolling contact fatigue (RCF). This project may be considered as a continuation of project MU11 but with more focus on resolving some basic issues. An in-depth investigation is 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 due to the rotating stress state during each single overrolling of the wheels. Of interest are geometrical parameters, see figure below, together with material properties including the wheel/rail and crack surface friction coefficients.



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

PhD student Johan Tillberg (middle; licentiate gained in June 2008) and his supervisors Professor Kenneth Runesson (left) and Docent Fredrik Larsson in project MU17. For a photo of Professor Lennart Josefson, see page 45

Both rate-dependent (viscous) and rate-independent laws for crack propagation are studied. A fundamental and core issue in the project is the proper formulation and finite element implementation of the crack-driving force in the elastoplastic field (with hardening) at the crack tip. The crack-driving force (generalized J-integral) is defined here in the context of "material forces" (also called "configurational forces"), which is a vectorial measure of the energy release rate due to a (virtual) variation of the position of the crack tip. A particular issue is the role of the material dissipation which is induced by configurational changes, such as crack advancement. The peak value of the J-integral during an overrolling was found to decrease with decreasing crack interspacing, a phenomenon called crack shielding.

Johan Tillberg presented his licentiate thesis (see below) at a seminar on 4 June 2008 and Professor Andreas Menzel from the Department of Mechanics at the University of Dortmund (Germany) introduced the discussion. Work on project MU17 continues with studies of the crack-driving force and global energy dissipation for multiple interacting cracks under multiple overloadings in an elastoplastic material, a situation which is characteristic for RCF in rails. One important question to be answered is how crack shielding affects the generated crack spacing. There is close collaboration between projects MU17 and MU20. The CHARMEC-voestalpine meetings, see page 94, held twice a year play the role of reference group meetings for project MU17.

MU17. (cont'd)

Johan Tillberg and Fredrik Larsson: On the role of material dissipation for the crack-driving force, *Proceedings 20th Nordic Seminar on Computational Mechanics (NSCM-20)*, Gothenburg November 2007, 4 pages (documented on CD)

Johan Tillberg: Multiple crack interaction with RCF loading, *15th Nordic Seminar on Railway Technology,* Hook (Sweden) May 2008, 1+12 pp (Summary and PowerPoint presentation. Documented on CD)

Johan Tillberg: Elastic-plastic fracture mechanics and RCF in rails, Licentiate Thesis, *Chalmers Applied Mechanics,* June 2008, 70 pp (introduction, summary and two appended papers)

Fredrik Larsson, Kenneth Runesson and Johan Tillberg: On the formulation and computation of configurational forces based on the rate of global dissipation, *IUTAM Symposium on Progress in the Theory and Numerics of Configurational Mechanics,* Erlangen (Germany) October 2008 (to appear in a special IUTAM volume. So far only documented on CD)

Johan Tillberg, Fredrik Larsson and Kenneth Runesson: A study of multiple crack interaction at rolling contact fatigue loading of rails, *IMechE Journal of Rail and Rapid Transit*, vol 223, no F4, 2009, pp 319-330

Fredrik Larsson, Kenneth Runesson and Johan Tillberg: On the sensitivity of the rate of global energy dissipation due to configurational changes, *European Journal of Mechanics – A/Solids*, vol 28, no 6, 2009, pp 1035-1050

Johan Tillberg, Fredrik Larsson and Kenneth Runesson: On the role of material dissipation for the crack-driving force (submitted for international publication)

Materials and maintenance – Material och underhåll (MU) – Werkstoff und Unterhalt – Matériaux et entretien

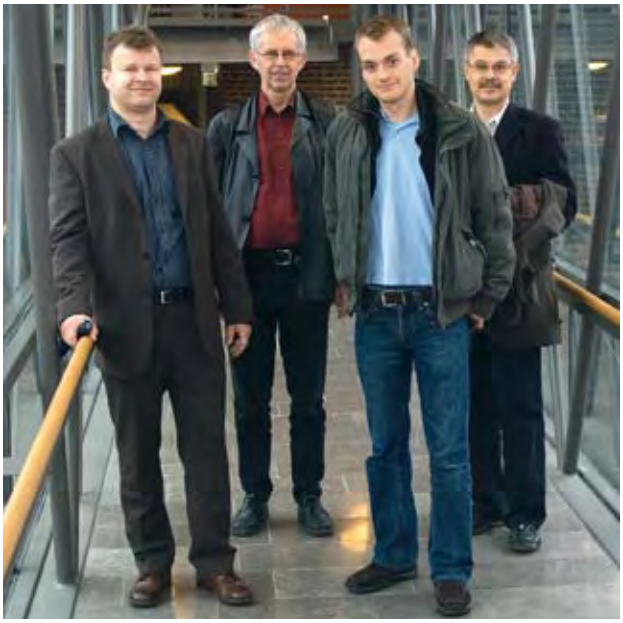
MU18. WHEELS AND RAILS AT HIGH SPEEDS AND AXLE LOADS

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 Material and Computational Mechanics
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)
Period	2006-04-18 – 2009-06-30 (–2011-04-17)
Chalmers budget (excluding university basic resources)	Stage 4: KSEK 375 Stage 5: KSEK 1750 Stage 6: KSEK 1650
Industrial interests in-kind budget	Stage 4: – Stage 5: KSEK 200+100+200 Stage 6: KSEK 200+100+200 *(Banverket+Bombardier Transportation+Lucchini Sweden)*

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

Plans currently exist in Sweden to increase both the maximum train speeds and maximum axle loads on the country's railways. This raises 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 because 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. Further, if problems with increased train speeds and axle loads arise in the future, there will be a need to quickly find and implement countermeasures. This calls for an understanding of damage mechanisms, an identification of root causes and a quantification of the gains provided by different countermeasures.



PhD student Johan Sandström (second from right; licentiate gained in October 2008) in project MU18 together with his supervisors Docent Anders Ekberg (left), Professor Jacques de Maré (second from left) and Professor Lennart Josefson. Photo taken in 2006

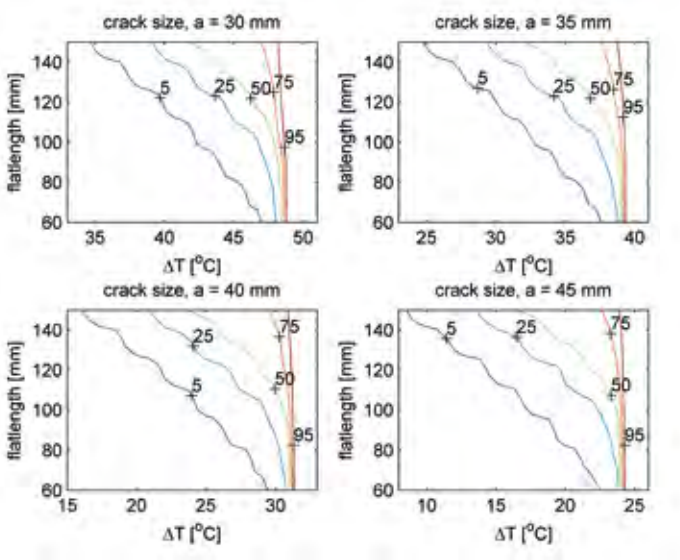
MU18. (cont'd)

Project MU18 focusses on topics that have been identified as cost drivers and includes aspects that prevent internationally found solutions (if such exist) from being directly applied to Swedish conditions. Some of the topics studied are: (i) optimal design of insulated rail joints, (ii) maintenance rules to prevent catastrophic failures of rails and wheels under upgraded operational conditions, and (iii) allowable material defects for wheels in high-speed operations. The present work benefits from several previous and parallel CHARMEC projects.

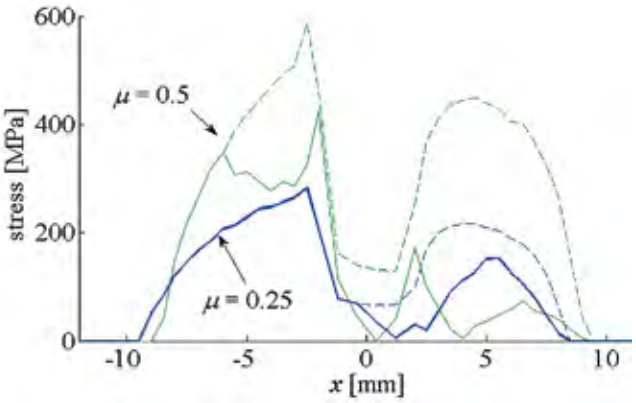
The initial focus in project MU18 has been on the probability of rail breaks under impact loads on the Iron Ore Line in northern Sweden, which was selected because of its well-defined operational characteristics. The influence of wheel flat impacts at random positions on the growth of existing rail cracks and on subsequent rail breaks has been investigated. To account for the high-frequency excitation due to the 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 was included, see diagrams. 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 smaller cracks.

The deterioration of insulating joints has also been studied. Repeated negotiations of a loaded wheel over an insulating joint were simulated using three-dimensional FE analysis of wheel and rail with an advanced elastoplastic constitutive model for the rail material. The results indicate that accumulated plastic strain (ratchetting) is the dominant damage mechanism for the connecting rail ends. In a parametric study, the influence of gap size, axle load, frictional force, and coefficient of maximum friction in the wheel/rail interface was assessed. In particular, the frictional force at traction and braking was found to have a major influence on joint deterioration. A limited field study of insulating joints has been carried out and has provided some qualitative confirmation of the simulations.

Johan Sandström presented his licentiate thesis (see below) at a seminar on 14 October 2008 with Anders Frick from Banverket introducing the discussion. The post-licentiate focus of project MU18 is on the fatigue of wheels at high speeds. Corrugation of rails and wheels together with wheel material defects are included in an analysis using the CHARMEC numerical toolboxes DIFF and FIERCE. With a statistical analysis of the resulting fatigue impact, a basis for determining allowable material defect sizes and suitable maintenance intervals for wheels can be laid. The joint reference group for projects MU18, MU21 and MU22 has members from Banverket, Bombardier Transportation (Siegen and Sweden), Interfleet Technology and SweMaint/Kockums Industrier. Additional members from Lucchini, Green Cargo and SL Technology are expected to join the group.



Calculated probabilities (%) of rail breaks as functions of gauge corner crack depth a, wheel flat length, and temperature ΔT below neutral temperature of rail



Calculated interfacial wheel/rail shear stresses [MPa] under a driven wheel passage from left to right at an insulating joint of width 4 mm (centred at $x = 0$) for two different maximum coefficients of friction, μ. Solid lines show interfacial shear stress. Broken lines show normal contact pressure scaled by μ (i e, μp). The vertical and longitudinal loads are 150 kN and 30 kN, respectively, for both of the two cases shown. Slip is occurring where the solid and broken lines coincide and stick where they differ

MU18. (cont'd)

Johan Sandström and Anders Ekberg: Predicting crack growth and risks of rail breaks due to wheelflat impacts in heavy haul operations, *Proceedings International Heavy Haul Association Specialist Technical Session (IHHA STS 2007)*, Kiruna (Sweden) June 2007, pp 379-388. Also printed in *IMechE Journal of Rail and Rapid Transit,* vol 223, no F2, 2009, pp 153-161

Johan Sandström, Anders Ekberg and Elena Kabo: Isolerskarvar – jämförelse mellan 4 mm och 8 mm skarvöppning (Insulated rail joints – a comparison between IRJ widths of 4 mm and 8 mm; in Swedish), Progress Report to Banverket, 6 pp

Johan Sandström: Low-cycle fatigue assessment of insulated rail joints from numerical simulations featuring contact and non-linear plastic hardening, *Proceedings 20th Nordic Seminar on Computational Mechanics (NSCM-20)*, Gothenburg November 2007, 3 pp (documented on CD)

Johan Sandström: Tracks and wheels for higher speeds and axle loads on Swedish railways, *15th Nordic Seminar on Railway Technology,* Hook (Sweden) May 2008, 1+22 pp (Summary and PowerPoint presentation. Documented on CD)

Johan Sandström: Analysis of rail breaks and insulated joint deterioration, Licentiate Thesis, *Chalmers Applied Mechanics,* Gothenburg October 2008, 58 pp (summary and two appended papers)

Johan Sandström and Anders Ekberg: A numerical study of the mechanical deterioration of insulated rail joints, *IMechE Journal of Rail and Rapid Transit,* vol 223, no F3, 2009, pp 265-273 (also listed under project EU10)

Jóhannes Gunnarsson: Numerical simulations of the plastic deformation of insulating joints, MSc Thesis 2009:15, *Chalmers Applied Mechanics,* Gothenburg 2009, 33 pp

Johan Sandström and Jacques de Maré: Probability of subsurface fatigue initiation in rolling contact, *Proceedings 8th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2009),* Florence (Italy) September 2009, vol 2, pp 419 - 424

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	Docent Magnus Ekh, Senior Lecturer, Applied Mechanics / Division of Material and Computational Mechanics
Assistant supervisors	Professor Kenneth Runesson and Docent Anders Ekberg, Applied Mechanics
Doctoral candidate	Ms Nasim Larijani, MSc (from 2009-06-22)
Period	2009-06-22–2009-06-30 (–2014-06-21)
Chalmers budget (excluding university basic resources)	Stage 5: KSEK 100 Stage 6: KSEK 2550
Industrial interests in-kind budget	Stage 5: KSEK 100+50+100 Stage 6: KSEK 100+50+400 *(Banverket+SL Technology +voestalpine Bahnsysteme)*

Rolling contact fatigue (RCF) will be studied with regard to the high degree of material anisotropy that predominates in the surface layer of railheads in the field. The anisotropy is believed to be the combined result of manufacturing operations at the rolling plant, frictional rolling contact loading in service and maintenance grinding. Mathematical models of the development of the anisotropy will be calibrated against laboratory experiments. The ultimate aim of project MU19 is to understand and predict the formation, orientation, interspacing and growth of head checks in the anisotropic environment on the railhead. Previous research results from projects MU11, MU14 and MU17 will be utilized. The research plan of project MU19 is dated 2006-11-22.

PhD student Nasim Larijani and her supervisors Docent Magnus Ekh (centre) and Docent Anders Ekberg. For a photo of Professor Kenneth Runesson, see page 53

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	Docent Magnus Ekh, Senior Lecturer, Applied Mechanics / Division of Material and Computational Mechanics
Assistant supervisors	Docent Fredrik Larsson and Docent Anders Ekberg, Applied Mechanics
Doctoral candidate	Mr Jim Brouzoulis, MSc (from 2007-12-01)
Period	2007-12-01–2009-06-30 (–2012-11-30)
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 1 300 Stage 6: kSEK 2 550
Industrial interests in-kind budget	Stage 5: kSEK 100+50+100 Stage 6: kSEK 100+50+400 *(Banverket+SL Technology +voestalpine Bahnsysteme)*

PhD student Jim Brouzoulis (right) and his supervisors Docent Fredrik Larsson (left) and Docent Magnus Ekh. For a photo of Docent Anders Ekberg, see page 47

Project MU20 investigates the interaction between wear and rolling contact fatigue (RCF) of rails. Wear influences RCF via removal of incipient cracks, via truncation of existing cracks and via a continuous change of the wheel/rail contact geometry. A redistribution of residual stresses in the rail may also occur. These phenomena are numerically simulated and experimentally calibrated. A refined model for rail profile updating to be used in conjunction with wear prediction will be developed. This model is expected to be of vital importance in integrated vehicle dynamics simulations. A central issue is the very large number of loading cycles that a rail has to endure. Project MU20 draws on several previous CHARMEC projects such as TS5, MU4, MU6, MU11 and MU12.

In a collaboration between projects MU17 and MU20, the propagation of a single head check crack under cyclic loading has been investigated. Calculations show that the crack tends to grow at a shallow angle until it reaches a certain critical depth where it changes direction to a steep angle. A computational tool for the simulation of rail wear in conjunction with plastic deformations has been developed. This tool combines Archard's law for wear with an elasto-plastic model for the rail steel.

Rail profile development due to wear and plastic deformation has been simulated in a collaboration with projects TS11 and MU20. Calibration is performed here against experimental data from voestalpine Schienen's test rig in Leoben (Austria).

The research plan for project MU20 is dated 2006-11-22. Meetings held twice a year with voestalpine Schienen and VAE, see page 94, play the role of reference group meetings for project MU20.

Jim Brouzoulis: Crack propagation in linear elasticity based on the concept of material forces, MSc Thesis 2007:60, *Chalmers Applied Mechanics,* Gothenburg 2007, 45 pp

Jim Brouzoulis, Fredrik Larsson, Johan Tillberg and Kenneth Runesson: Crack propagation in linear elasticity based on the concept of material forces, *Proceedings 20th Nordic Seminar on Computational Mechanics (NSCM-20)*, Gothenburg November 2007, 3 pp (documented on CD)

Jim Brouzoulis: Fatigue crack propagation in rails, *15th Nordic Seminar on Railway Technology,* Hook (Sweden) May 2008, 1+27 pp (Summary and PowerPoint presentation. Documented on CD)

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, *Proceedings 8th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2009),* Florence (Italy) September 2009, vol 2, pp 701 - 710 (also listed under project TS11)

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 Material and Computational Mechanics
Assistant supervisors	Docent Elena Kabo, Docent Magnus Ekh and Dr Tore Vernersson, Applied Mechanics
Doctoral candidate	Mr Håkan Hansson, MSc (2008-01-01 to 2008-09-19)
	Ms Sara Caprioli, MSc (from 2009-06-01)
Period	2008-01-01–2009-06-30 (–2014-05-31)
Chalmers budget (excluding university basic resources)	Stage 5: KSEK 700 Stage 6: KSEK 2550
Industrial interests in-kind budget	Stage 5: KSEK 50+200+100 Stage 6: KSEK 50+200+100 *(Bombardier Transportation +Green Cargo+SweMaint)*

For photos of the supervisors in project MU21, see pages 48, 50 and 59

Project MU21 aims at an improved model for predicting surface-initiated rolling contact fatigue (RCF) 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 will affect the material properties (decreased yield limit, increased ductility, higher propensity for wear) and induce residual stresses and surface cracks on cooling. These effects will be quantified and included in a predictive model. Project MU21 draws on previous and parallel CHARMEC projects, such as MU4, MU9, MU10, MU18 and MU20.

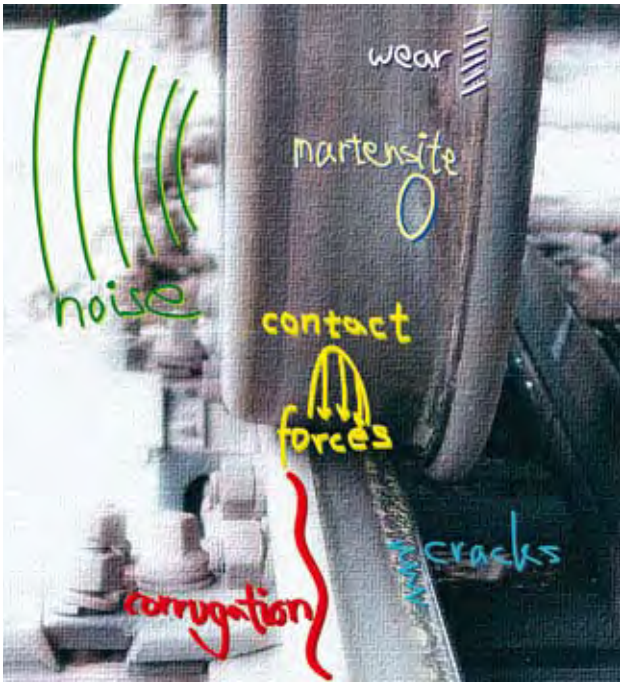
Preliminary studies have shown that two-dimensional models are not feasible. Consequently, methods to minimize the computational effort are a main priority. Three-dimensional models have been developed and simulations have been carried out for the case of a Hertzian contact load travelling over the tread of a wheel. A first study has been conducted to establish required geometrical size, boundary conditions and constitutive models.

The research plan for project MU21 is dated 2006-11-22. For the joint reference group for projects MU18, MU21 and MU22, see under MU18.

PhD student Sara Caprioli in project MU21

Håkan Hansson and Anders Ekberg: Thermal impact on RCF of wheels, *15th Nordic Seminar on Railway Technology,* Hook (Sweden) May 2008, 1+18 pp (Summary and PowerPoint presentation. Documented on CD)

Tore Vernersson, Elena Kabo, Håkan Hansson and Anders Ekberg: Wheel tread damage – a numerical study of railway wheel tread plasticity under thermomechanical loading, *Proceedings 9th International Heavy Haul Conference (IHHA2009)*, Shanghai (China) June 2009, vol I, pp 465-472



Phenomena related to wheel/rail contact

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 Material and Computational Mechanics
Co-workers	Docent Elena Kabo and Professor Roger Lundén, Applied Mechanics
Doctoral candidate	None (only senior researchers in this project)
Period	2007-07-01–2009-06-30 (–2012-06-30)
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 700 Stage 6: kSEK 200
Industrial interests in-kind budget	Stage 5: kSEK 100+200+100 Stage 6: kSEK 50+100+50 *(Bombardier Transportation +Lucchini Sweden+SweMaint)*

Professor Roger Lundén (left), Docent Elena Kabo and Docent Anders Ekberg in project MU22

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 current project aims to refine the predictive models in FIERCE. Work on project MU10 is thereby continued.

Work in project MU22 up until the present includes the prediction of subsurface initiated RCF owing to operations featuring corrugated rails and/or out-of-round wheels, derivation of a simplified criterion for prediction of subsurface RCF from measured contact forces, a feasibility study of bainitic wheels, and an analysis of the influence of hollow-worn wheel treads on the risk of subsurface initiated RCF. This work has been carried out in collaboration with colleagues at KTH in Stockholm, MTAB in Kiruna, Lucchini in Italy and Transnet in South Africa.

A number of damage analyses and improvement studies have also been conducted under the umbrella of project MU22. Roger Lundén, Björn Paulsson and Anders Ekberg have been invited to contribute to the upcoming "Wheel/Rail Interface Handbook", see page 92. Elena Kabo has been appointed Docent, see page 80.

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

Anders Ekberg, Elena Kabo, Jens Nielsen and Roger Lundén: Subsurface initiated rolling contact fatigue of railway wheels as generated by rail corrugation, *International Journal of Solids and Structures*, vol 44, no 24, 2007, pp 7975–7987 (also listed under projects TS8 and SP11)

Anders Ekberg: Helsingfors tunnelbana – rullkontaktutmattning hos tunnelbanehjul (Helsinki metro – rolling contact fatigue of metro wheels; in Swedish), *Chalmers Applied Mechanics*, Gothenburg 2007, 5 pp (availability restricted)

Robert Fröhling, Anders Ekberg and Elena Kabo: The detrimental effects of hollow wear – field experiences and numerical simulations, *Wear*, vol 265, nos 9-10, 2008, pp 1283-1291

Andrea Gianni, Andrea Ghidini, Tord Karlsson and Anders Ekberg: Bainitic steel grade for solid wheels: metallurgical, mechanical, and in-service testing, *IMechE Journal of Rail and Rapid Transit*, vol 223, no F2, 2009, pp 163-171. Also presented at the conference *IHHA STS 2007* in Kiruna (Sweden) on 11-13 June 2007

Elena Kabo, Roger Enblom and Anders Ekberg: Assessing risks of subsurface initiated rolling contact fatigue from field measurements, *Proceedings 8th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2009)*, Florence (Italy) September 2009, vol 1, pp 355 - 361 (also listed under project SP11)

MU23. MATERIAL BEHAVIOUR AT RAPID THERMAL PROCESSES

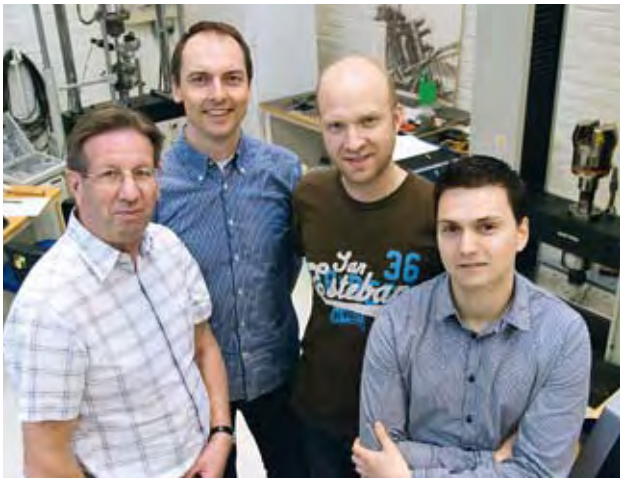
Materialbeteende vid snabba termiska förlopp
Materialverhalten bei schnellen thermischen Prozessen
Comportement des matériaux sous processus thermiques rapides

Project leaders and supervisors	Professor Birger Karlsson and Dr Johan Ahlström, Senior Lecturer, Materials and Manufacturing Technology
Doctoral candidate	Mr Krste Cvetkovski, MSc (from 2007-10-15)
Period	2007-10-01–2009-06-30 (–2012-10-14)
Chalmers budget (excluding university basic resources)	Stage 5: KSEK 2600 Stage 6: KSEK 4950
Industrial interests in-kind budget	Stage 5: KSEK 100+200 Stage 6: KSEK 100+300 *(Banverket + voestalpine Bahnsysteme)*

This is a combined senior and doctoral project

Phenomena behind thermal damage on wheels and rails can be malfunctioning anti-skid devices, uneven 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 experiments and numerical models.

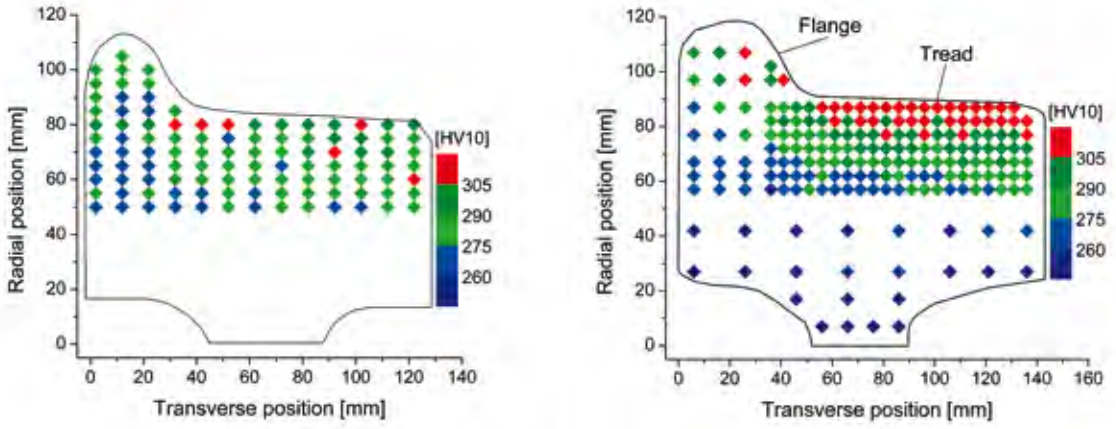
As encouraged by the reference group (see below) an investigation has been performed on a pearlitic carbon wheel steel with increased silicon and manganese content. Laboratory tests show that the new material, in its virgin material state, has a slightly shorter fatigue life at room temperature and a somewhat lower impact toughness as compared to the corresponding wheel material of type R8T (EN 13262:2004). Comparing the hardness of the two wheel steels it was found that the R8T has up to 10 percent higher hardness in the outer portion of the rim of the wheel, see figure.



PhD students Krste Cvetkovski (right) in project MU23 and Martin Schilke (second from the right) in project MU24 and their supervisors Professor Birger Karlsson (left) and Dr Johan Ahlström

To simulate short time thermal processes, heating in a furnace and radiation with a high-energy laser will be used. Contacts has been made with the Materials Science Centre at Leoben (Austria) concerning rapid laser heat treatments of the wheel material in order to simulate heat shocks experienced in practice. The laboratory tests will be combined with investigations on wheels taken out of service. The research plan of project MU23 is dated 2007-01-22. The reference group for project MU23 includes members from Banverket, Bombardier Transportation (Sweden and Siegen) and Interfleet Technology.

Krste Cvetkovski, Johan Ahlström and Birger Karlsson: Monotonic and cyclic deformation of a high silicon pearlitic wheel steel, *Proceedings 8th International Conference of Contact Mechanics and Wear of Rail/Wheel Systems (CM2009)*, Florence (Italy) September 2009, vol 2, pp 557 - 563



Hardness testing (HV10) of High Silicon Manganese (left) and R8T (right) steels

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 Birger Karlsson and Dr Johan Ahlström, Senior Lecturer, Materials and Manufacturing Technology
Doctoral candidate	Mr Martin Schilke, MSc (from 2007-10-15)
Period	2007-10-01–2009-06-30 (–2012-10-14)
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 1500 Stage 6: kSEK 2850
Industrial interests in-kind budget	Stage 5: kSEK 100+300 Stage 6: kSEK 100+300 *(Banverket + voestalpine Bahnsysteme)*

For a photo of Birger Karlsson, Johan Ahlström and Martin Schilke, see page 51

The competitiveness of railway transportation calls for longer rail life. This is a challenging demand today because the deterioration of rail material 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. The study includes both rolling contact fatigue (RCF) as developed in tests of rails on a full-scale fatigue rig and well-defined laboratory low cycle fatigue (LCF) tests.

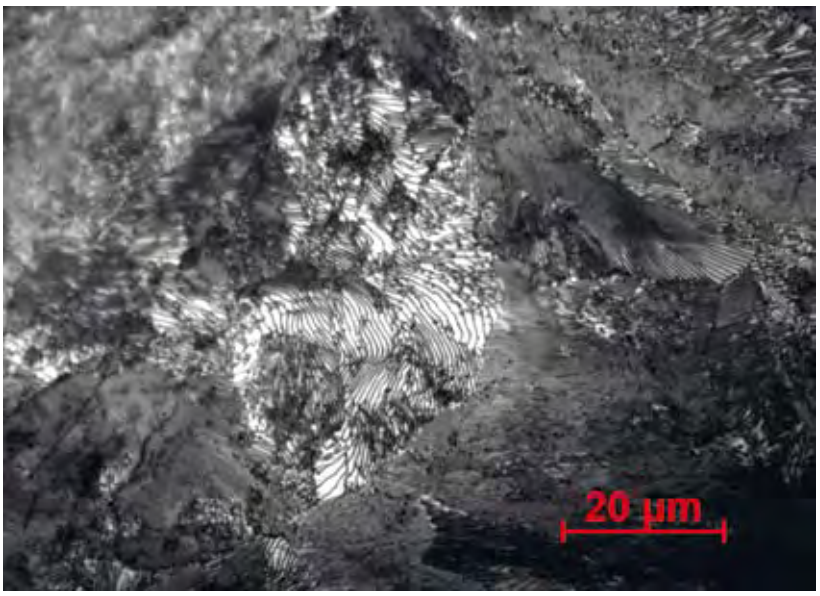
The experimental activities in project MU24 are conducted at Chalmers (LCF) and voestalpine (RCF) in Leoben (Austria). Samples of material from the R350HT (head hardened) and 400 UHC (Ultra High Carbon) pearlitic steels are provided by voestalpine together with documentation on chemical composition, sulphur content and segregation.

The sulphide distribution through a whole cross section of a R350HT rail has been recorded and evaluated.
It was found that manganese sulphides (MnS) are rarer in the head than in the web and foot of the rail. Other slags than MnS, mainly oxides, were also observed but these are very infrequent. Preliminary LCF test results have shown a cyclic deformation behaviour resembling that of the pearlitic steel R260 (UIC900A) but with some 30% higher stress response levels for identical strain amplitudes. Further LCF evaluations and fractographic examinations (including crack patterns on sample surfaces and cross sections) of the R350HT material will follow. New materials will be investigated regarding their LCF and RCF properties.

The research plan for project MU24 is dated 2007-01-22. Testing of switch rail materials for project EU10 in autumn 2009 (financed separately from INNOTRACK, see project EU10) will delay the work in MU24 by about six months. The reference group for project MU24 has members from Banverket and voestalpine Schienen.

Johan Ahlström, Birger Karlsson, Martin Schilke and Krste Cvetkovski: Materialteknisk forskning inom CHARMEC – stål i hjul, räler och växlar (Research in material technology within CHARMEC – steel in wheels, rails and switches; in Swedish), *15th Nordic Seminar on Railway Technology,* Hook (Sweden) May 2008, 1+12 pp (Summary and PowerPoint presentation. Documented on CD)

Johan Ahlström, Martin Schilke and Birger Karlsson: Monotonic and cyclic deformation of medium and high strength rail steels, *Proceedings 8th International Conference of Contact Mechanics and Wear of Rail/Wheel Systems (CM2009),* Florence (Italy) September 2009, vol 1, pp 3 - 5



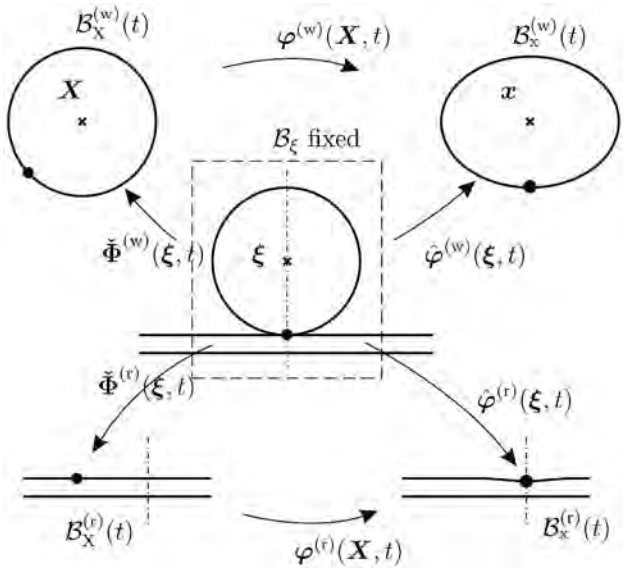
Microstructure of the fully pearlititc rail steel 350HT

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 leaders and supervisors	Docent Anders Ekberg, Docent Fredrik Larsson and Professor Kenneth Runesson, Applied Mechanics / Division of Material and Computational Mechanics
Doctoral candidate	Mr Andreas Draganis, MSc (from 2009-06-29)
Period	2009-01-01–2011-12-31 (and an expected prolongation by 30 months)
Chalmers budget (excluding university basic resources)	Stage 5: – Stage 6: KSEK 2400
Industrial interests in-kind budget	Stage 5: – Stage 6: –

The project is financed by The Swedish Research Council, VR



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

In the application to VR this research project was titled "Computational modelling of thermodynamical coupling for contacting bodies in high-speed relative motion". One practical example to be investigated in project MU25 is a railway wheel moving along the rail while being braked. In an accurate study of the contact zone, the rapid rise of the frictional heat combined with the high contact stresses may motivate the use of a refined constitutive equation for the material where the thermodynamical coupling is being considered. An efficient finite element strategy based on a space/time variational formulation is foreseen for the motion of the two bodies. Validation against experimental data will be made. Martensitic transformation of the material (see projects MU3 and MU23) may be included.

PhD student Andreas Draganis (second from the right) and his supervisors Docent Anders Ekberg (left), Docent Fredrik Larsson (second from the left) and Professor Kenneth Runesson in project MU25

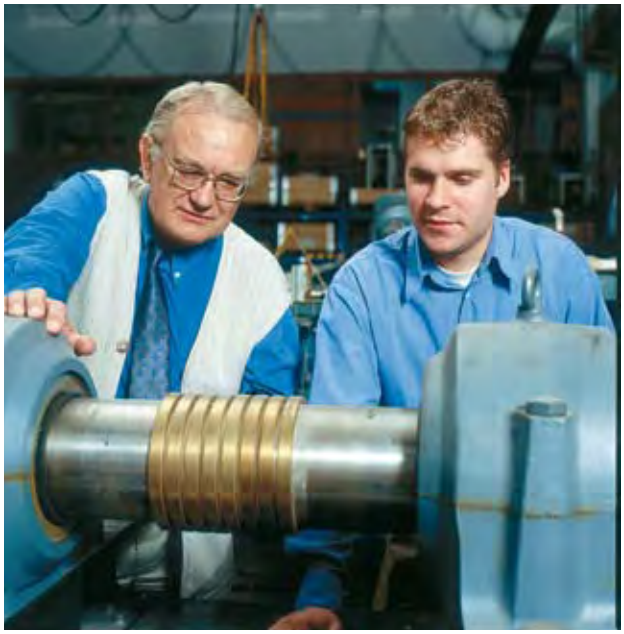
SD1. BRAKING OF FREIGHT TRAINS – A SYSTEMS APPROACH

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

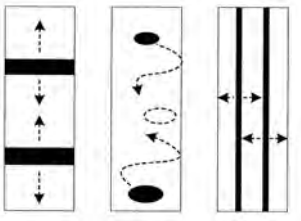
The SD1 project was completed with Daniel Thuresson's successful defence in public of his doctoral dissertation in October 2006. The faculty-appointed external examiner of the dissertation was Professor Andrew Day of the School of Engineering, Design & Technology at the University of Bradford in West 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 57 and 60) 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

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

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

Systems for monitoring and operation – System för övervakning och drift (SD) – Systeme für Überwachung und Betrieb – Systèmes pour surveillance et opération

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".

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.

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.

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 63

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 (see page 57).

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

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

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.

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 and 4. The articles below were printed after the latter report was edited. The reference group for project SD4 included members from SAB WABCO / Faiveley Transport and Interfleet Technology.

Tore Vernersson: Temperatures at railway tread braking. Part 1: modelling, *IMechE Journal of Rail and Rapid Transit*, vol 221, no F2, 2007, pp 167-182

Tore Vernersson: Temperatures at railway tread braking. Part 2: calibration and numerical examples, *ibidem*, vol 221, no F4, 2007, pp 429-441

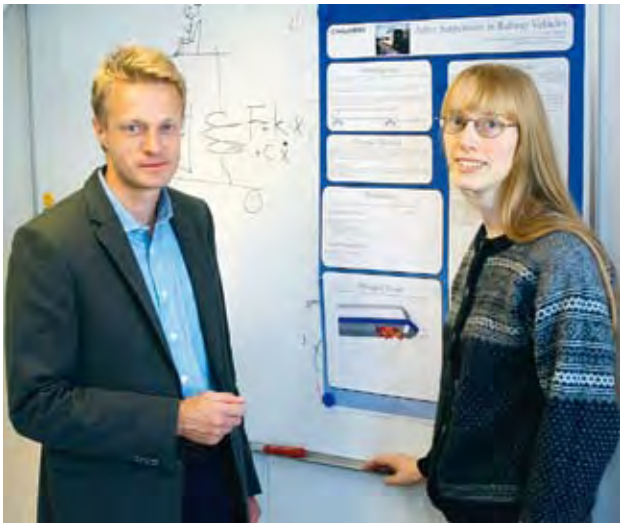
Tore Vernersson and Roger Lundén: Temperatures at railway tread braking. Part 3: wheel and block temperatures and the influence of rail chill, *ibidem*, vol 221, no F4, 2007, pp 443-454

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 and 4. Jessica Fagerlund presented her licentiate thesis (see below) at a seminar on 8 June 2009 and Dr Anna-Karin Christensson from University West in Trollhättan (Sweden) introduced the discussion.



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

Jessica Fagerlund: Towards active car body suspension in railway vehicles, Licentiate Thesis, *Chalmers Signals and Systems*, Gothenburg June 2009, 122 pp

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:

$2m$	v_0	s_{sign}	s_b	t_b	r	Q_0	E	D	n	M
tonnes	km/h	m	m	s	m/s^2	kW	kWh	m	rpm	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

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'autre composants de chemin de fer

Project leaders and supervisors	Professor Viktor Berbyuk and Docent Mikael Enelund, Applied Mechanics / Division of Dynamics
Doctoral candidate	Mr Albin Johnsson, MSc (from 2008-03-03)
Period	2008-03-01 – 2009-06-30 (–2013-02-28)
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 1000 + 200 Stage 6: kSEK 2700
Industrial interests in-kind budget	Stage 5: – Stage 6: kSEK 400 *(Bombardier Transportation)*

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

Active components are becoming accepted for railway vehicles. Full exploitation in wheelset suspension systems is potentially radical because this could change the basic mechanical arrangement to which the railway industry has been accustomed. Although the general principles of active secondary suspensions are now well established, a number of areas still require further research, particularly in active vibration control. Improved suspension performance will result in better ride quality for passengers. 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. A parallel objective will be to reduce track degradation and track maintenance costs.

The aim of project SD6 is two-fold: Firstly, to provide an overview of the potential of so-called smart-materials actuators and technology for sensing and actuating in active vibration control for high-speed trains. Secondly, to develop novel methodologies and mathematical models together with efficient algorithms for application in high-speed train bogies. A literature study on conventional railway solutions, semi-active and active technologies and different control strategies has been carried out. Of special interest are MagnetoRheological (MR) dampers.

The research plan for project SD6 is dated 2008-03-01. The joint reference group for projects TS12 and SD6 consists of members from Bombardier Transportation Sweden and Interfleet Technology.

Albin Johnsson, Viktor Berbyuk and Mikael Enelund: Optimized bogie system damping with respect to safety and comfort, *Poster at 21st IAVSD Symposium on Dynamics of Vehicles on Roads and Tracks (IAVSD2009)*, Stockholm (Sweden) August 2009

PhD student Albin Johnsson (centre) and his supervisors Professor Viktor Berbyuk (left) and Docent Mikael Enelund 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

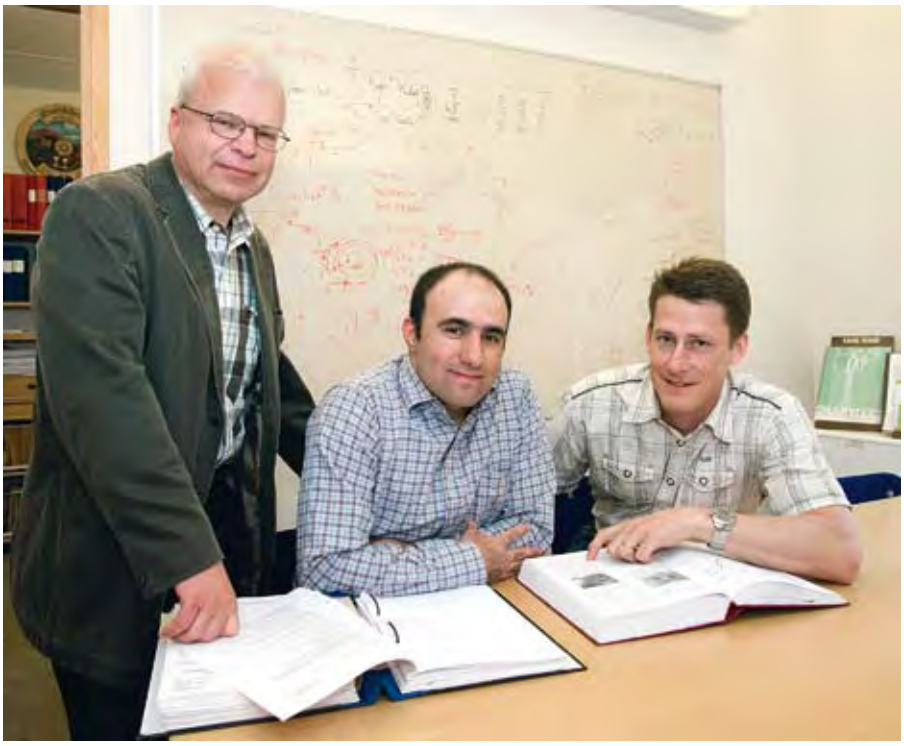
Project leaders and supervisors	Professor Roger Lundén and Dr Tore Vernersson, Applied Mechanics / Division of Dynamics
Doctoral candidate	Mr Shahab Teimourimanesh, MSc (from 2008-09-22)
Period	2008-09-01 – 2009-06-30 (–2013-09-30)
Chalmers budget (excluding university basic resources)	Stage 5: KSEK 600 Stage 6: KSEK 2550
Industrial interests in-kind budget	Stage 5: KSEK 100 + 300 + 50 + 200 Stage 6: KSEK 100 + 300 + 50 + 400 *(Bombardier Transportation + Faiveley Transport + Interfleet Technology + Lucchini Sweden)*

The thermal capacity of the wheels puts a limit to railway tread braking systems. In project SD7, the range of tread braking applications will vary from light, medium and heavy metro applications to mainline coach and freight locomotive applications with the focus being on wheels for metros where frequent stop braking occurs. Results from the previous project SD4 on the heat partitioning between brake block, wheel rim and rail will be used.

With exception for the drag braking cases described in the European standard EN 13979-1, there are no known standards in the public domain regarding the thermal capacity limits for wheels. In-service rejection criteria (e g, maximum residual stress levels) for wheels that have endured a (potential) overheating event also require consideration. The present project should develop methods and provide data that can form a basis for future design guidelines. Mathematical modelling, rig experiments and field tests will be included.

A literature study has been conducted on heat partitioning at repeated stop braking and on the thermal capacity of wheels. Models for the thermal capacity will be implemented and evaluated using the commercial finite element software ABAQUS. Tore Vernersson and Shahab Teimourimanesh participated in brake rig tests that were carried out by Faiveley Transport in April 2009 together with Federal Mogul Corporation at Chapel-en-le-Frith in Derbyshire, UK.

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 (Siegen/ Germany, Sweden and UK), Faiveley Transport, Interfleet Technology and SL Technology.



PhD student Shahab Teimourimanesh (centre) and his supervisors Professor Roger Lundén (left) and Dr Tore Vernersson in project SD7

SD8. WEAR OF DISK 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 – 2009-06-30 (–2010-12-31)
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 1200 Stage 6: kSEK 700
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 59

As observed in revenue operations, the main part of the life cycle costs 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. Project SD8 studies the thermomechanical interaction and wear in disk brakes and block brakes. The aim is to reduce weights and life cycle costs, and to improve braking performance.

Mathematical and numerical models are being developed and calibrated to data from parallel rig experiments and field tests. The models should 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 the maintenance costs. Flytoget in Norway and SL Metro C20 in Stockholm have been chosen as reference cases for axle-mounted disks and tread brakes, respectively.

The research plan for project SD8 is dated 2007-05-18. 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 Technology.

Tore Vernersson and Roger Lundén: Temperatures at railway tread braking – a parametric study, *15th Nordic Seminar on Railway Technology,* Hook (Sweden) May 2008, 1+21 pp (Summary and PowerPoint presentation. Documented on CD)

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 56

EUROSABOT

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 where our Hans Johansson assisted.

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

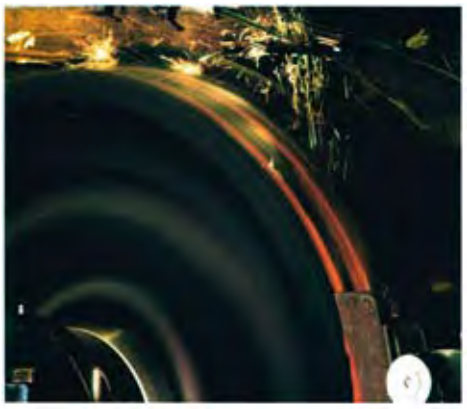


Photo of a cast-iron brake block in operation on the test rig at Surahammar in projects SD1 and EU1

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 24

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 disk 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 disk) 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 24

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.

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 45

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.

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

For a photo of project leader Roger Lundén, see page 59

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)

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 50 and 24

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

EU6. (cont'd)

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 disk 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 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 and EU10 , the additional costs at Chalmers are reported as "Budget CHARMEC".

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

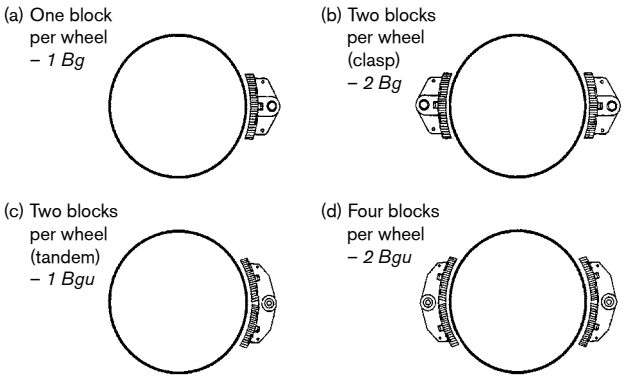
For photos of project leaders Lennart Josefson and Roger Lundén and their co-workers Jens Nielsen, Jonas Ringsberg and Birger Karlsson, see pages 24, 36, 45 and 51

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.

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.



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)

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 59 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 63), 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 × 1685 Stage 6: KEUR 0.5 × 1685

For a photo of Roger Lundén and Anders Ekberg, see page 50

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

EU9. (cont'd)

(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", and his role included attending the Business Case Workshop at UIC in Brussels on 31 August 2006, participating in the Integration Congress and the EURNEX stand at the INNOTRANS Fair in Berlin on 17-21 September 2006, presenting EURNEX to the UIC Technology Support Group on 7 November 2006, and presenting comments on the proposed new ERRAC Strategic Rail Research Agenda. Version 2 of the Pole 8 position paper has now been finalized, see below. A EURNEX Pole 8 workshop was held in Paris on 13 February 2007 in connection with the UIC Track Expert Group meeting. See also CHARMEC's Triennial Report for Stage 4.

Astrid Pieringer from project VB10 was accepted to the EURNEX mentor programme for female PhD students in the railway sector, and she spent 13-16 November 2007 with Professor Stefano Bruni at Sezione di Meccanica dei Sistemi at Politecnico di Milano in Italy.

EURNEX: Position paper on railway infrastructure and signalling, Version 2 of 22 July 2006, *Chalmers Applied Mechanics*, Gothenburg 2006, 50 pp

EU10. INNOTRACK

INNOTRACK – Innovative Track Systems

Project leader	Professor Roger Lundén, Applied Mechanics/ Division of Dynamics
Co-workers	Dr Johan Ahlström
	Dr Mats Ander
	Mr Jim Brouzoulis, MSc
	Docent Anders Ekberg
	Docent Magnus Ekh
	Docent Elena Kabo
	Professor Birger Karlsson
	Docent Fredrik Larsson
	Dr Anders Johansson
	Dr Göran Johansson
	Professor Jens Nielsen
	Mr Björn Pålsson, MSc
	Professor Kenneth Runesson
	Mr Johan Sandström, Lic Eng
	Mr Martin Schilke, MSc
	Mr Johan Tillberg, Lic Eng
	Professor Bengt Åkesson
Period	2006-09-01 –2009-12-31
Budget EU	KEUR 560 + 52
Budget CHARMEC	KSEK 3 085+1 500

Chalmers / CHARMEC is a partner in the INNOTRACK project. This is an Integrated Project (IP) under the Sixth Framework Programme: Thematic Priority 6 – Sustainable Development, Global Change and Ecosystems. The aim is to

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

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 objective of reducing the rate of track degradation and maintenance intervention. See www.innotrack.eu.

Lower LCC (Life Cycle Costs) and improved RAMS (Reliability, Availability, Maintainability and Safety) characteristics are the goal. Common European practices for LCC and RAMS evaluations are being established. Subprojects (SP) of INNOTRACK are SP0 Project management (led by UIC with

EU10. (cont'd)

Banverket's Björn Paulsson as Project Manager based at the UIC office in Paris), SP1 Duty / Requirements (led by Network Rail), SP2 Track support structure (led by SNCF), SP3 Switches and crossings (led by DB), SP4 Rails and welding (led by Corus and VAS), SP5 Logserv (led by Alstom), SP6 LCC assessment (led by DB), and SP7 Dissemination and training (led by UIC). CHARMEC's Anders Ekberg is the technical and scientific co-ordinator of INNOTRACK. His work is financed by Banverket, CHARMEC, UIC and VINNOVA (KSEK 300+300+600+300=1500 included in Budget CHARMEC' above).

INNOTRACK comprises a total of 1266 man-months with a budgeted project cost of MEUR 18.6 (including budgeted EU funding of MEUR 10.0). The duration of the project is 36+4 months. Chalmers / CHARMEC's commitment is 40 (+4) man-months with EU funding KEUR 560 (plus KEUR 52 for additional material testing). The person responsible for the launching of INNOTRACK at the European Commission was William Bird. The current EU officer is Adam Grodzicki.

The 36 partners (from 10 countries) in INNOTRACK are listed in CHARMEC's Triennial Report for Stage 4. Among them are Banverket, Chalmers/CHARMEC and Damill AB from Sweden, and CHARMEC's partners voestalpine Schienen (VAS above) and VAE from Austria. During the course of the work, CHARMEC's personnel have taken part in some 100 meetings in Sweden and abroad with our European partners. Additional financing (KSEK 3085) from Banverket and Chalmers covers the difference between CHARMEC's full costs for INNOTRACK and EU funding.

CHARMEC is involved in two subprojects: SP3, where low and high-frequency simulations of train/switch interaction are combined with local non-linear FE calculations to derive contact stress distributions and predict plastic deformation, wear and cracking of rails and wheels; and SP4, where rules are established for optimizing the choice of maintenance intervals and, where possible, preventing operational interventions in the event of rail corrugation or rail cracks, for example. CHARMEC has also been involved in the definition of more relevant tests for the classification of rail steels, and is now performing new tests. EU10 has also benefitted from our analytical, numerical and experimental work in several other CHARMEC projects, both concluded and ongoing.

The ten INNOTRACK countries

The results of the INNOTRACK project are being accounted for in about 140 "deliverables" to be concluded before 31 December 2009. CHARMEC is the lead contractor for 6 of these and contributes to others. All manuscripts of deliverables are being reviewed and this process is co-ordinated by Anders Ekberg. Many of the deliverables will be published on INNOTRACK's website (www.innotrack.eu). A Concluding Technical Report that

Some of the CHARMEC researchers involved in project EU10. Upper row (from the left): Elena Kabo, Anders Ekberg, Bengt Åkesson, Anders Johansson, Roger Lundén, Magnus Ekh and Johan Ahlström. Bottom row (from the left): Johan Tillberg, Jim Brouzoulis, Jóhannes Gunnarsson (MSc student), Johan Sandström, Björn Pålsson, Mats Ander, Martin Schilke and Jens Nielsen

EU10. (cont'd)

summarizes the overall results of INNOTRACK is scheduled for early 2010.

As already mentioned under project MU22, Roger Lundén and Björn Paulsson have been invited to write an introductory chapter in the upcoming Wheel/Rail Interface Handbook, see page 92.

Björn Paulsson: INNOTRACK – Innovative Track Systems – a unique approach by infrastructure managers and the competitive track supply industry for developing the innovative products of the future (Keynote Speech), *Proceedings International Heavy Haul Association Specialist Technical Session (IHHS STS 2007)*, Kiruna (Sweden) June 2007, pp 5-15

Elias Kassa and Jens Nielsen: Dynamic interaction between train and railway turnout – full-scale field tests and validation of simulation models, *Vehicle System Dynamics,* vol 46, nos 1-2, supplement 1, 2008, pp 521-534. Also presented at *20th IAVSD Symposium* in Berkeley CA (USA) August 2007 (also listed under project TS7)

Jens Nielsen: Rail roughness level assessment based on high-frequency wheel/rail contact force measurements, presented at *9th International Workshop on Railway Noise (IWRN9)* in Feldafing/Munich (Germany) September 2007. With an abbreviated version in *Notes on Numerical Fluid Mechanics and Multidisciplinary Design,* vol 99 (Noise and Vibration Mitigation for Rail Transportation Systems), Springer, Berlin 2008, pp 355-362 (also listed under project SP11)

Ulla Espling and Anders Ekberg: INNOTRACK – INNOvative TRACK systems, *15th Nordic Seminar on Railway Technology,* Hook (Sweden) May 2008, 1+39 pp (Summary and PowerPoint presentation. Documented on CD)

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, *Proceedings 8th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2009)*, Florence (Italy) September 2009, vol 3, pp 987 - 996

Jens Nielsen and Anders Ekberg: Acceptance criterion for rail roughness level spectrum based on assessment of rolling contact fatigue and rolling noise, *ibidem,* vol 2, pp 409 - 418

Björn Paulsson, Peter Pointner, Jay Jaiswal, Rob Carroll, Gunnar Baumann, Burchard Ripke, John Amoore and Anders Ekberg: An overview of wheel-rail interface related research in the European project INNOTRACK including issues in technical and economical validation, *ibidem,* vol 2, pp 535-537 (plus a later supplementing up to 8 pages)

Björn Paulsson, Anders Ekberg and Francis Delooz: Results to exemplify the joint EU-project INNOTRACK – Innovative Track Systems, *Proceedings 9th International Heavy Haul Conference (IHHA2009)*, Shanghai (China) June 2009, vol I, pp 128-134

Johan Sandström and Anders Ekberg: A numerical study of the mechanical deterioration of insulated rail joints, *IMechE Journal of Rail and Rapid Transit,* vol 223, no F3, 2009, pp 265-273 (also listed under project MU18)

Deliverables INNOTRACK TIPS-CT-031415:

Jens Nielsen (editor): Summary of results from simulations and optimization of switches, D 3.1.4, 2008, 35 pp (and 4 annexes, 16 +13 +25 +21 pp)

Jens Nielsen (editor): Summary of final results from optimization and recommendations for S & C design, Part I, D 3.1.5, 2009 (in preparation)

Jens Nielsen (editor): Summary of final results from optimization and recommendations for S & C design, Part II, D 3.1.6, 2009 (in preparation)

Anders Ekberg (editor): Simplified relation for the influence of rail/joint degradation on operational loads and subsequent deterioration, D 4.2.1, 2007, 22 pp (and 10 annexes, 27+25+10+12+6+8+7+7+25+4 pp)

Anders Ekberg (editor): Improved model for loading and subsequent deterioration of insulated joints, D 4.2.3, 2009, 19 pp (and 1 annex, 17 pp)

Zili Li (editor): Improved model for loading and subsequent deterioration due to distributed rail defects (e g, squats and rail corrugation), D 4.2.4, 2009, 33 pp (and 5 annexes, 7+10+8+26+26 pp)

Francis Franklin (editor): Improved model for the influence of vehicle conditions (wheel flats, speed, axle load) on the loading and subsequent deterioration of rails, D 4.2.5, 2009, 47 pp (and 6 annexes, 47+15+9+22+35+53 pp)

Elena Kabo (editor): Simulation of material deformation and RCF, D 4.3.5, 2009, 42 pp (and 2 annexes, 20+17 pp)

EU11. QCITY

Quiet City Transport

This is an Integrated Project (IP) under the Sixth Framework Programme: Thematic Priority 6 – Sustainable Development, Global Change and Ecosystems. Banverket is 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.

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). Our personnel have assisted the Lucchini company on a continuous basis in the design, analysis, testing, documentation and marketing of wheelsets. The main contact people have been Lennart Nordhall, Ulf Edvinson and Niclas Eriksson of Lucchini Sweden at Surahammar, and Jürgen Schneider and Francesco Lombardo of Lucchini Sidermeccanica at Lovere/Lombardy (Italy). In April 2009, Erik Kihlberg succeeded Lennart Nordhall as President of Lucchini Sweden. New contact people at Surahammar are now also Gunnar Eriksson and Peter Jöehrs. A new wheel for 25 tonne axle load has recently been designed, tested and patented, and approved by UIC. The wheelset also complies with the requirements of the TSI (Technical Specifications for Interoperability). The following paper presents a late investigation.

Roger Lundén, Tore Vernersson and Anders Ekberg: Railway axle design – to be based on fatigue initiation or crack propagation?, *Proceedings 9th International Heavy Haul Conference (IHHA 2009)*, Shanghai (China) June 2009, vol I, pp 509-517

SP2. NOISE FROM SWEDISH RAILWAYS

CHARMEC has been involved in Banverket's 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.

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, 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.

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). As of Stage 3, the two Austrian companies have 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

Project leader	Docent Anders Ekberg, Applied Mechanics / Division of Material and Computational Mechanics
Co-workers	Dr (now Docent) Elena Kabo, Applied Mechanics, and Dr Erland Johnson, Mr Lars Jacobsson, Lic Eng, Dr Gunnar Kjell and Dr Robert Lillbacka, all four of SP Technical Research Institute of Sweden
Period	2003-01-01–2007-06-30
Chalmers budget (excluding university basic resources)	Stage 3: KSEK 300+335 Stage 4: KSEK 365+2500 Stage 5: –

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 ultimate goal of project SP7 was to find methods for predicting and preventing the occurrence of sun-kinks.

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. Several existing and proposed methods for measuring the axial force (and thereby the neutral temperature) in an installed rail have been studied theoretically, numerically and experimentally. A proposed "wave guide method" was tested at the SP laboratory, see photo. In this method (where a tensile axial force is assumed) some of the fastenings are decoupled, the rail is harmonically excited in the lateral direction and the length of the propagating vibrational bending wave, or the wave number, is (indirectly) measured. The axial force is then found via the ratio between the measured wave number and the calculated wave number for the same rail with zero axial force.

Photo: Frida Hedberg, Aftonbladet

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

SP7. (cont'd)

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 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 have been 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. An existing constitutive model for ballast resistance, see project MU1, was developed and implemented as a user-defined element for the FE program ABAQUS to simulate the coupling between sleepers, ballast and ground.

Finally, a "track resonance method" was launched for an experimental study of the overall risk of sun-kinks on an existing track. Here the full track should be laterally excited by use of a hydraulic shaker, for example, and the lowest resonance frequency be measured. Lateral instability will be impending when this frequency is close to zero. An attempt to extract this frequency from the vibrations caused by passing regular train traffic was not successful. A continuation of work with the "track resonance method" is ongoing at SP.

Elena Kabo and Anders Ekberg: Numerisk prediktering av uppkomst av solkurvor – modellering, analys, inledande parameterstudie samt indatagenerering (Numerical prediction of the formation of sun-kinks – modelling, analysis, preliminary parametric study and input data generation; in Swedish), Research Report 2007:02, *Chalmers Applied Mechanics,* Gothenburg 2007, 16 pp

Anders Ekberg and Elena Kabo: PRESOL – pre-processor för solkurveanalys (PRESOL – pre-processor for sun-kink analysis; in Swedish), Research Report 2007:03, *ibidem,* 11 pp

Erland Johnson, Gunnar Kjell, Lars Jacobsson, Robert Lillbacka, Anders Ekberg and Elena Kabo: Lateral spårstabilitet – slutrapport (Lateral track stability – final report; in Swedish), Research Report 2007:04, *ibidem,* 31 pp

Elena Kabo and Anders Ekberg: Preventing sun-kinks, *15th Nordic Seminar on Railway Technology*, Hook (Sweden) May 2008, 1+16 pp (Summary and PowerPoint presentation. Documented on CD)

Gunnar Kjell and Erland Johnson: Measuring axial forces in rail by forced vibrations – experiences from a full-scale laboratory experiment, *IMechE Journal of Rail and Rapid Transit,* vol 223, no F3, 2009, pp 241-254

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

SP8. DESIGN OF INSULATED JOINTS

Utformning av isolerskarvar

Project leader	Dr (now Docent) Elena Kabo, Applied Mechanics / Division of Material and Computational Mechanics
Co-worker	Professor Jens Nielsen, Applied Mechanics
Period	2004-07-01–2007-06-30
Chalmers budget (excluding university basic resources)	Stage 4: KSEK 100+100 Stage 5: KSEK 200

For photos of Elena Kabo and Jens Nielsen, see pages 24 and 50

Work in project SP8 has been shifted to projects TS8, MU18 and EU10, see under these projects.

Elena Kabo, Jens Nielsen and Anders Ekberg: Prediction of dynamic train-track interaction and subsequent material deterioration in the presence of insulated rail joints, *Vehicle System Dynamics,* vol 44, no 1, supplement 1, 2006, pp 718-729 (also listed under projects TS8 and MU9)

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, 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. For a photo of Jens Nielsen and Rikard Bolmsvik, see page 78. See also CHARMEC's Triennial Report for Stage 4 and projects SP12 and SP17 in the following.

Rikard Bolmsvik and Jens Nielsen: Ny sliper för 35 tons axellast (New sleeper for 35 tonne axle load; in Swedish), *15th Nordic Seminar on Railway Technology*, Hook (Sweden) May 2008, 1+18 pp (Summary and PowerPoint presentation. Documented on CD)

SP10. NOISE REDUCTION MEASURES AND EU PROJECT QCITY

Bullerreducerande åtgärder och EU-projektet QCITY

Project leader	Professor Jens Nielsen, Applied Mechanics / Division of Dynamics
Co-workers	Mr Nicolas Renard, Mr Jan Spännar, Lic Eng, Mr Simon Gripner and Ms Karin Blidberg, all four of Banverket
Period	2005-01-01–2009-06-30
Chalmers budget (excluding university basic resources)	Stage 4: KSEK 300+300+200 Stage 5: KSEK 600

For a photo of Jens Nielsen, see page 79

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 focussing on railway noise have therefore been run at Banverket. 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

SP10. (cont'd)

project QCITY (Quiet City Transport) comprising a total of 1041 man-months and with budgeted EU funding of MEUR 7.40 (here Banverket is 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 92. The aim of SP10 was to increase efficiency and achieve synergy effects by integrating these projects. The task was assigned to CHARMEC's Jens Nielsen.

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. Rail roughness and Track Decay Rate (TRD in dB/m) were measured by Banverket. Rail vibrations and railway noise at 7.5 m from track centre were measured at four sections (three sections with rail dampers and one reference section without rail dampers). The noise measurements were performed by company Acoustic Control according to standard ISO 3095.

The track sections at Tjörnarp with Corus and S&V dampers resulted in a TDR in the vertical direction that favourably exceeded the required TSI (Technical Specifications for Interoperability) limit for an approved reference track in all measured 1/3 octave bands. The increase in TDR compared to the track section without rail dampers was significant. Noise and rail vibrations from 18 train passages (6 X2, 8 Öresund and 4 freight trains) were recorded. On average for the X2 trains, the S&V dampers resulted in a 1.9 dB(A) reduction in Transit Exposure Level (TEL) whereas the Corus dampers generated a 1.2 dB(A) reduction. For the Öresund trains, the S&V dampers resulted in a 1.9 dB(A) reduction in TEL while the Corus dampers generated a 2.1 dB(A) reduction. For the four freight trains, the Corus dampers consistently resulted in a 3 dB(A) reduction. An investigation of the TEL noise spectra generated by the passenger trains concluded that the noise to a large extent was dominated by a contribution from the 1/3 octave bands with centre frequencies 2.0 and 2.5 kHz. This contribution was excited by rail marks with wavelengths in the order of 2 cm remaining from the grinding operation. None of the dampers was efficient at such high frequencies where the contribution from the wheels to the total noise emission is large.

Earlier tests (without dampers) carried out before and after rail grinding at the Tjörnarp site showed very good results: an expected moderate 1.5 dB(A) reduction in sound pressure level (SPL) was observed for freight trains with cast-iron brake blocks, whereas the reduction for disk braked trains was considerable (6 dB(A) for X2 trains and 8 dB(A) for Öresund trains). On average, noise levels measured 7.5 m from track centre and 1.2 m above rail were 88 dB(A) for Öresund trains, 94 dB(A) for X2 trains and 98 dB(A) for freight trains.

A low barrier designed by company Zbloc Norden was installed at a test track near Kungsängen north-west of Stockholm. The nominal height of the barrier is 0.73 m above the upper surface of the rail. The inner face of the top section of the barrier is positioned 1.70 m from track centre. The side of the barrier facing the track is covered with an absorber made of rubber and plastic. Railway noise was measured in October 2008 at three sections (two of them with barrier and one without barrier) at 7.5 and 10 m from track centre. Rail roughness was measured by Banverket. The speed of all passing trains was limited to 70 km/h.

In total, noise from 14 train passages (8 X60, 2 X40, 1 X12, 2 InterCity and 1 freight train) was recorded at Kungsängen. Without a noise barrier, the X60 and X40 trains were the quietest trains measured, some 8 dB(A) quieter than the freight train. The barrier was found to be most efficient in reducing TEL for the X60 and X12 trains. The reduction in total noise level was some 8 to 9 dB(A). The barrier was less efficient, 4 to 6 dB(A), for the X40, InterCity and freight trains. The reason for this is that the X60 and X12 have sidewalls enclosing the rail car underneath (bogies not included). The combination of a low barrier and trains with their noisy equipment enclosed underneath the rail car was found to be an efficient solution for reducing noise. Bogie skirts mounted on the train would enhance the acoustic performance of the low barrier even more.

The results from the field tests at Tjörnarp and Kungsängen have been summarized in two deliverables submitted to the QCITY consortium, see below. Jan Spännar and

Dampers from Corus Rail UK mounted at the Tjörnarp test site

SP10. (cont'd)

Jens Nielsen participated in the final seminar of the Dutch innovation programme on railway noise in Doorn (the Netherlands) on 9-10 December 2008. Jens Nielsen attended the final meting of QCITY in Rome (Italy) on 16 January 2009. A final report of the work performed in project SP10 has been written, see below. A post-processor to TWINS containing roughness level spectra measured for different wheel types and different track sections has been delivered to Banverket and Bombardier Transportation. Noise maps and action plans for railway lines with more than 60 000 train passages per year have been developed in accordance with the EU Noise Directive 2002/49/EC. These results have been assembled in a GIS-based database. See also CHARMEC's Triennial Report for Stage 4.

Jens Nielsen: Banverkets FUD-projekt med fokus på rullkontaktbuller – status januari 2007 och förslag på fortsättning (Banverket's research projects on rolling noise – status January 2007 and suggestions for continued research; in Swedish), Research Report 2007:06, *Chalmers Applied Mechanics,* Gothenburg 2007, 17 pp

Jan Spännar: Tillståndsbedömning av räfflor och vågor med hjälp av tersbandsdiagram (Assessment of rail roughness in third-octave bands; in Swedish), Report BVH 1588, *Banverket*, Borlänge (Sweden) 2008, 28 pp

Jan Spännar: A new approach of assessing rail roughness, *Proceedings 4th International Conference on Railway Condition Monitoring,* Derby (UK) June 2008, 5 pp (documented on CD)

Jens Nielsen, Oskar Lundberg and Nicolas Renard: Performance report of applied measures – Malmö – in-field measurements of the influence of combined wheel and rail damping on railway noise, Deliverable 5.9, part 1 / QCITY, *EU Sixth Framework Programme* / Contract no TIP4-CT-2005-516420, 41 pp and 2 appendices

Jens Nielsen, Oskar Lundberg and Nicolas Renard: Performance report of applied measures – Malmö – in-field measurements of the influence of low barrier on railway noise, Deliverable 5.9, part 2 / QCITY, *ibidem*, 23 pp and 1 appendix

Jens Nielsen: Rullningsljud – FUD-projekt vid Banverket 2005–2008 (Rolling noise – Banverket's research projects 2005–2008; in Swedish), Research Report 2009:05, *Chalmers Applied Mechanics*, Gothenburg 2009, 30 pp

Jan Spännar: Measured rail corrugation growth, *Proceedings 8th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2009),* Florence (Italy) September 2009, vol 2, pp 429-432

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 and Professor Jens Nielsen, 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 Stage 6: KSEK 200
Industrial interests in-kind budget	Stage 5: KSEK 730 *(Interfleet Technology)*

Project SP11 was part of the Green Train Programme in Sweden, see page 92. The full SP11 project contained the following ten tasks: (1) refinement of a computer-based tool to analyse measured data from project SP3, (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, (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 database BIS, and (10) dissemination through written reports and oral presentations. The project was a collaboration between Interfleet Technology and CHARMEC. CHARMEC have been involved in tasks 2, 4, 5, 8 and 10.

Vertical contact forces measured by use of Interfleet Technology Test Centre's instrumented wheelset have been compared to contact forces calculated with DIFF. Good agreement between measured and calculated forces generated by rail corrugation and periodic transients was observed, with respect to both magnitude and frequency content, for most frequency bands below 2000 Hz. The best agreement was obtained when using a model that accounted for both of the two wheelsets in a bogie, instead of using a single wheelset model.

Root mean square (rms) values of simulated and measured vertical wheel/rail contact forces were calculated for

SP11. (cont'd)

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, now SL), Roger Lundén (CHARMEC), Tohmmy Bustad (Banverket), Lennart Warsén (SJ), Lars Andersson (Interfleet), Jens Nielsen (CHARMEC) and Simon Gripner (Banverket)

different combinations of train speed and rail corrugation level. After band-pass filtering with cut-off wavelengths 3 cm and 8 cm, these rms values have been found to be an efficient indicator for the detection of track sections with short-pitch rail corrugation. Such an assessment will be profitable when planning rail grinding intervals if used together with a system for regular monitoring of rail roughness levels.

A simplified criterion of subsurface initiated rolling contact fatigue (RCF) for in-field test analysis has been derived. This criterion is based solely on measured vertical contact loads and an estimated rail head radius, and can thus be used to relate measured vertical forces to RCF impact without any further assumptions. An extension of the criterion to mildly curved track has later been performed.

The reference group for project SP11 included members from Banverket, CHARMEC, Interfleet Technology and SJ AB. Work on an acceptance criterion for rail surface quality has been continued in project EU10. Interfleet Technology received an additional grant from Banverket for their development work on a tool for analysing large quantities of data produced when measuring track forces with high-frequency resolution. For our work on task 8 above, see projects MU11, MU18 and MU22. See also CHARMEC's Triennial Report for Stage 4.

During Stage 6, the Green Train Programme (see page 92) will be further dealt with in project SP11. Using registered vertical wheel/rail contact forces together with the results of CAT (Corrugation Analysis Trolley) measurements on the test stretches, CHARMEC's interaction model DIFF will be applied and developed. The influence of speed on the vertical contact forces is an important issue for the coming high-speed train.

Anders Ekberg, Elena Kabo, Jens Nielsen and Roger Lundén: Subsurface initiated rolling contact fatigue of railway wheels as generated by rail corrugation, *International Journal of Solids and Structures,* vol 44, no 24, 2007, pp 7975-7987 (also listed under projects TS8 and MU10)

Anders Ekberg and Elena Kabo: The influence of vertical load transients on wheel and rail deterioration, Research Report 2007:12, *Chalmers Applied Mechanics,* Gothenburg 2007, 20 pp

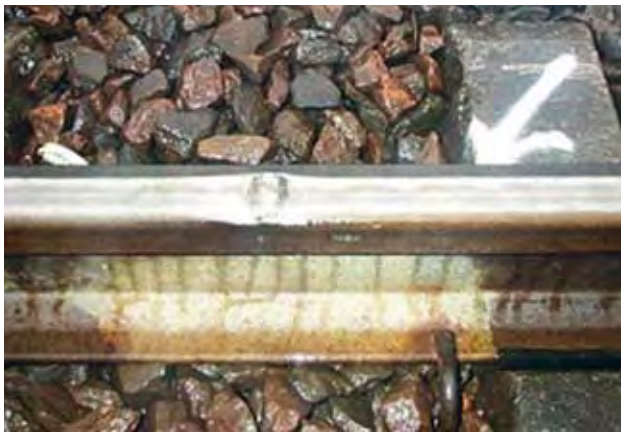
Elena Kabo and Anders Ekberg: Index for real-time prediction of sub-surface initiated rolling contact fatigue in railway wheels, Research Report 2007:13, *ibidem,* 12 pp

Jens Nielsen: Rail roughness level assessment based on high-frequency wheel-rail contact force measurements, presented at *9th International Workshop on Railway Noise (IWRN9)* in Feldafing/Munich (Germany) September 2007. With an abbreviated version in *Notes on Numerical Fluid Mechanics and Multidisciplinary Design,* vol 99 (Noise and Vibration Mitigation for Rail Transportation Systems), Springer, Berlin 2008, pp 355-362 (also listed under project EU10)

Jens Nielsen: High-frequency vertical wheel-rail contact forces – validation of a prediction model by field testing, *Wear,* vol 265, nos 9-10, 2008, pp 1465-1471 (revised article from conference *CM2006*. Also listed under project TS8)

Per Gullers, Lars Andersson and Roger Lundén: High-frequency vertical wheel-rail contact forces – field measurements and influence of track irregularities, *Wear,* vol 265, nos 9-10, 2008, pp 1472-1478 (revised article from conference *CM2006*)

Elena Kabo, Roger Enblom and Anders Ekberg: Assessing risks of subsurface initiated rolling contact fatigue from field measurements, *Proceedings 8th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2009),* Florence (Italy) September 2009, vol 1, pp 355-361 (also listed under project MU22)



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

SP12. NEW SLEEPER SPECIFICATIONS

Nya sliperspecifikationer

Project leader	Professor Jens Nielsen, Applied Mechanics / Division of Dynamics
Co-worker	Dr Rikard Bolmsvik, Abetong
Period	2006-07-01–2006-12-31
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 450

For a photo of Jens Nielsen and Rikard Bolmsvik, see page 78

Project SP12 was initiated by Banverket and based on previous work in project SP9. The design of sleepers for 35 tonne axle load was to be 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 influence of wheel tread defects (wheel flats) and the non-uniform distribution of support stiffness from the ballast along the sleeper has been studied. The bending moments in the sleeper at the rail seats and centre have been 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 on the Iron Ore Line in September 2006 were also utilized, see project TS9. Sleepers with cracked and non-cracked centre sections were studied and the risk for fatigue failure was evaluated using statistics gathered through Banverket's wheel damage detector at Harrträsk. The proposed dimensioning bending moments 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. Today's corresponding values for 25 tonne axle load are 15 kNm and -9 kNm.

SP13. ALARM LIMITS FOR WHEEL DAMAGE

Larmgränser för hjulskador

Project leader	Professor Jens Nielsen, Applied Mechanics / Division of Dynamics
Co-workers	Docent Anders Ekberg and Docent Elena Kabo, Applied Mechanics
Period	2006-10-01–2009-06-30
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 300+220

For photos of Jens Nielsen, Anders Ekberg and Elena Kabo, see pages 24 and 50

The criterion in Sweden for removing wheels with a flat has hitherto been based on the length of the flat, which may not exceed 40 mm or 60 mm. In the latter case, immediate action is required. To find a more rational alternative, project SP13 has focussed on the maximum contact force that a damaged wheel may exert on the rail. In Banverket's existing wayside detectors, the lowest alarm limit has been set at 290 kN.

New alarm limits should consider the risk of rail fracture caused by a damaged wheel. The present study has 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 have been used.

Results from the field test with a train (our so-called "horror train") containing several intentional and severe wheel defects, which was performed on Svealandsbanan in September 2000 (see project TS5 in CHARMEC's Triennial Report for Stage 2), have been reanalysed. In particular, measured peak bending moments in the rail caused by wheel flats have been compared with calculated results using DIFF.

In the new study, different types of traffic (axle load, axle distance and train speed) were considered. For each of three train types (Malmbanan with 30 tonnes and 60 km/h, freight with 25 tonnes and 100 km/h, and X40 with 21 tonnes and 200 km/h) and for given magnitudes of the impact load, the strategy was to identify worst-case scenarios with respect to (i) the time history of the impact load and (ii) the impact position with reference to the position of a pre-existing crack. The study also considered the case where one or several adjacent sleepers are hanging from the rail. A non-linear track model in DIFF was employed here. It was assumed, as a severe case, that a hanging sleeper does not make contact with the ballast until it has been displaced 2 mm in the vertical direction.

SP13. (cont'd)

The agreement between measured and calculated rail bending moments caused by wheel flats was acceptable. Significant negative rail bending moments (tension in the rail head) are generated midway between the two wheelsets of a bogie when one of the wheels has a flat. Maximum positive bending moments (tension in the rail foot) are generated where the flat strikes the rail. It was found that the tensile stress in both head and foot of the rail increases with decreasing rail pad stiffness. As expected, the bending moments increase considerably with hanging sleepers.

Derived bending moments were translated into stress intensity factors for pre-existing cracks in the head and foot of the rail. Inspection intervals and detectability of rail cracks were discussed. A preliminary version of a crack propagation code is ready. Results from the current project SP13 have been transferred to INNOTRACK project EU10 to facilitate international input, synergy and adoption.

Jens Nielsen, Elena Kabo and Anders Ekberg: Larmgräns för hjulskadedetektorer – en utredning av risk för rälbrott på Malmbanan (Alarm limit for wheel damage detectors – an investigation of risk of rail fracture on the Iron Ore Line; in Swedish), Research Report 2007:05, *Chalmers Applied Mechanics,* Gothenburg 2007, 40 pp

Jens Nielsen, Anders Ekberg and Elena Kabo: Alarm limits for wheel flats, *15th Nordic Seminar on Railway Technology,* Hook (Sweden) May 2008, 1+27 pp (Summary and PowerPoint presentation. Documented on CD)

Elena Kabo, Anders Ekberg and Jens Nielsen: Analysis of static fractures of rails due to wheel flats, Research Report 2009:01, *Chalmers Applied Mechanics,* Gothenburg 2009, 18 pp

Jens Nielsen, Elena Kabo and Anders Ekberg: Alarm limits for wheel-rail impact loads, part 1: rail bending moments generated by wheel flats, Research Report 2009:02, *Chalmers Applied Mechanics,* Gothenburg 2009, 31 pp

Anders Ekberg, Elena Kabo and Jens Nielsen: Alarm limits for wheel-rail impact loads, part 2: analysis of crack growth and fracture, Research Report 2009:03, *ibidem,* 49 pp

SP14. PARTICLE EMISSIONS AND NOISE FROM RAILWAYS

Partikelemissioner och buller från järnväg

Project leaders	Professor Erik Fridell, IVL Swedish Environmental Research Institute, and Docent Anders Ekberg, Applied Mechanics / Division of Material and Computational Mechanics
Co-worker	Professor Roger Lundén, Applied Mechanics
Period	2007-01-01–2009-06-30
Chalmers budget (excluding university basic resources)	Stage 5: KSEK 100

Particle emissions will probably be one of the dominating health aspects of railway (and road) traffic in coming decades. Mechanisms contributing to emissions are the continuous wear of wheels and rails, especially on curves, the temporary wear of brake blocks, brake pads and brake disks, and the wear of catenary wires and pantograph contact strips. Important parameters for the health impact are the size distribution and chemical composition of the particles.

This project had two main objectives. One was to measure the emission of particles from railways in order to analyse the environmental impact. The other was to investigate the possibility of developing methods to measure wear on wheels, brakes and rails by measuring particle emissions and noise under various conditions (train type, speed, acceleration, braking, curve radius, weather, etc).

The budget of the total project is KSEK 1525 of which Banverket contributes KSEK 820. There has been collaboration and synergies with a parallel project "Health effects in the lung from particles in the Stockholm underground" (Swedish: "Hälsoeffekter i luftvägar från partiklar i Stockholms tunnelbana") performed by Karolinska Institutet in Stockholm and financed by Banverket. A joint reference group (led by Malin Kotake of Banverket) was established for the current project and the parallel project at Karolinska Institutet.

Particle emissions and air flow have been registered at the entrance/exit of a single-track tunnel at Hindås on the Western Main Line for a large number of trains. Onboard measurements of particles and noise have been performed for Regina trains travelling between Stockholm and Västerås, between Göteborg and Kalmar and between Göteborg and Halmstad. The position of the train (and indirectly train speed and acceleration) was monitored by GPS.

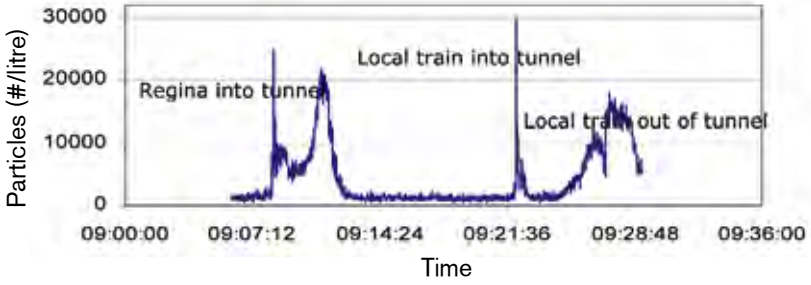
Large variations in the number of particles emitted were observed. High peaks, especially in the number of smaller

SP14. (cont'd)

particles, can be correlated to mechanical braking (here disk braking). The level of particle emission also shows a slight correlation to track curvature. The tunnel measurements have produced emission factors for PM10 (Particle Matter suspended in air with an aerodynamic diameter of up to 10 micrometer). A major effort was put into making all instruments work simultaneously while unattended for several days.

CHARMEC's main input to the project was an analysis of the correlation between particle emission and wear. Stationary observations were found to enable the identification of trains with a high emission of particles but the precision was not good enough to assess track access charges based on measured emission levels. The studies indicate, however, that particle emission sensors could be very efficient for detecting malfunctioning and/or poorly adjusted braking systems. The detection of wheels and bogies with poor steering is also likely.

Erik Fridell, Martin Ferm, Anders Björk and Anders Ekberg: Emissions of particulate matter from railways – onboard and tunnel measurements, *IVL Swedish Environmental Research Institute,* Report B1892, Stockholm 2009, 42 pp



Example of result from tunnel measurements at Hindås in project SP14

SP15. COMPUTER PROGRAM FOR DESIGN OF BLOCK BRAKES

Beräkningsprogram för utformning av blockbromsar

Project leader	Dr Tore Vernersson, Applied Mechanics / Division of Dynamics
Co-worker	Professor Roger Lundén, Applied Mechanics
Period	2007-07-01–2008-12-31
Chalmers budget (excluding university basic resources)	Stage 5: KSEK 600
Industrial interests in-kind budget	Stage 5: KSEK 100 *(Faiveley Transport)*

For a photo of Tore Vernersson and Roger Lundén, see page 59

In this project, results from the previous project SD4 have been implemented in an industrially adapted computer code. Candidate mathematical models found during a literature survey were compared and the possible benefits and drawbacks were listed and ranked with respect to their capability to mimic results from the accurate (but rather complex and time-consuming) finite element (FE) model developed in project SD4. The selected "simplified model", which has been implemented in MATLAB, uses the Finite Difference Method (FDM) on implicit form. It can capture most of the key features of the FE model, but still allows fast analyses on a standard laptop computer. The input of the wheel geometry to the program is taken from a generic wheel geometry or from a drawing.

The "simplified model" for calculating wheel and block temperatures can be used to efficiently design tread braking systems for both freight and passenger trains. It can handle stop braking and drag braking and also intermediate periods of cooling. The temperature history during a full train route can thus be calculated. The basic thermal model is being refined and further developed in project SD7. The plan for project SP15 is dated 2007-05-18.

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. Results from the software have also been used to assess the required speed limitations if some components of the total brake system of a train malfunctioned and other components had to perform an increased braking effort without being overloaded.

Tore Vernersson: Tread braking of railway wheels – dimensioning wheel temperatures, Software manual version 1.0, *Chalmers Applied Mechanics / CHARMEC*, Gothenburg December 2008, 45 pp

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

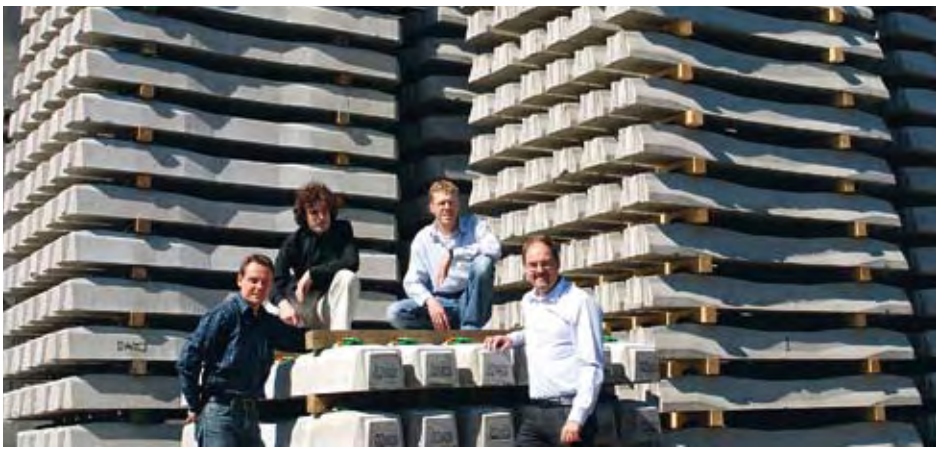
Identifiering av dynamiska egenskaper i spår hos träsliprar och ersättningssliprar av betong

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
Industrial interests in-kind budget	Stage 5: –

For a photo of Tore Vernersson and Roger Lundén, see page 59

The joint initiative for project SP16 came from Abetong and Banverket, and these two parties also share financing on an equal basis. New timber sleepers, often impregnated with creosote, may have to be avoided in the future, and this situation together with the need for replacing single (cracked or rotten) timber sleepers in an existing track forms the background for the project.

The properties of timber sleepers in track will be measured. Based on these measurements and numerical simulations, a concrete replacement sleeper will be designed and tested. Important issues are preserved vertical stiffness and lateral stability of the track. The plan for project SP16 is dated 2008-11-04. Master's student Nico Burgelman is assisting in the project.



From the left: Mikael Thuresson of Abetong together with Nico Burgelman, Rikard Bolmsvik and Jens Nielsen at a visit to Abetong's sleeper plant at Vislanda (Sweden) in project SP16

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

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	2009-01-15–2009-12-31
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 609
Industrial interests in-kind budget	Stage 5: –

For photos of Rikard Bolmsvik, Jens Nielsen and Elias Kassa, see above and on page 18

Concrete line-sleepers for axle load 35 tonnes were studied in project SP12. According to plans, Banverket will now introduce specifications for the sleepers in switches (turnouts) of a track where a 35 tonne axle load is foreseen. In particular, the required bending moment capacity of these sleepers should be determined. Banverket finances project SP17.

Results from the measurements at Härad on Svealandsbanan in May 2006, and from new measurements at Eslöv on the Southern Main Line are being utilized together with numerical simulations using the codes DIFF3D and GENSYS. Project SP17 is co-ordinated with project EU10. The plan for project SP17 is dated 2009-02-05.

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
Period	2009-03-01–2009-12-31
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)*

The objective of project SP18 is to identify the most important rolling stock parameters in the process of generating and propagating ground vibrations from railways. Numerical simulations with codes SIMPACK and TGV (the latter developed by ISVR in UK) are being performed, and experimental results from full-scale test runs with the Regina train are being utilized. Acceptable limits for wheel out-of-roundness (see project TS5) with respect to ground vibrations will be calculated, for example. The influence of track parameters may also be studied more closely.

Important vehicle parameters may be total wagon mass, bogie mass, unsprung mass, wheel resilience, wheel roughness, wheel out-of-roundness, primary and secondary suspension stiffnesses and dampings, stearing system, car body vibrational modes, vehicle speed, and geometrical interrelations such as axle distance relative to sleeper spacing.

The present project originates in the 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 11 countries and led by Deutsche Bahn). This IP (Integrated Project) application under the Second Call of the Seventh Framework Programme was rejected. A new application under the Third Call is envisaged. The plan for project SP18 is dated 2008-12-08.

Project SP18 meeting on 11 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

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 2009).

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

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	2005-10-28
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

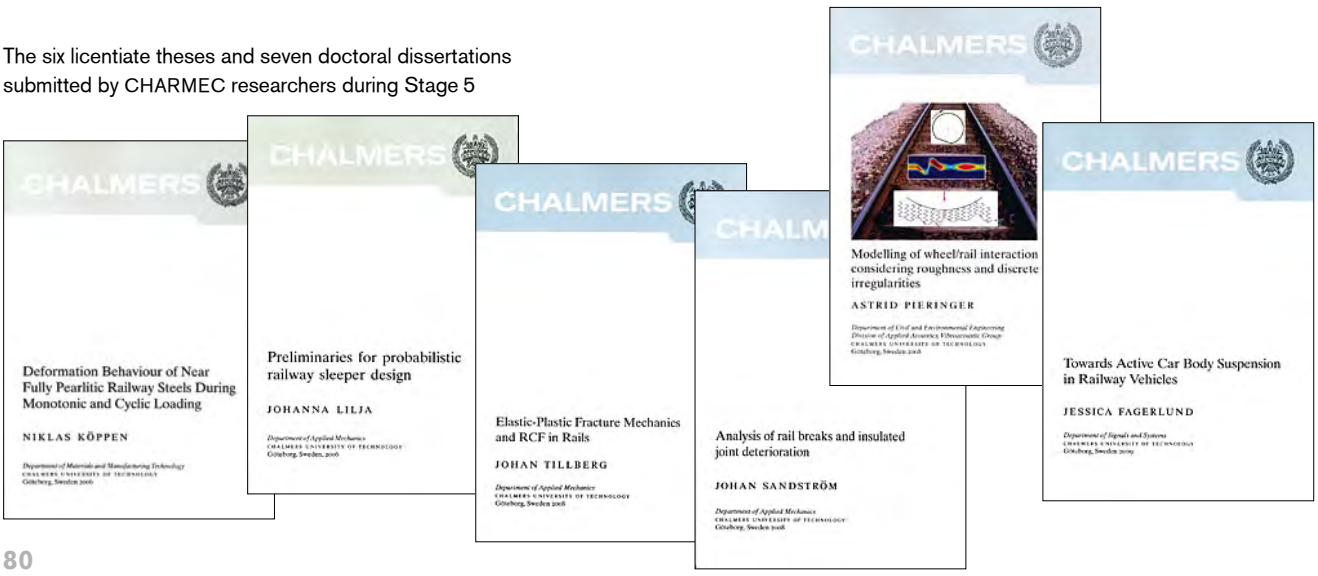
Docent (highest academic qualification in Sweden)

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

Adjunct Professor

Jens Nielsen	2006-07-01

The six licentiate theses and seven doctoral dissertations submitted by CHARMEC researchers during Stage 5



INTERNATIONAL CONFERENCES

During Stage 5 (and the months immediately following Stage 5) researchers from CHARMEC have participated in, and contributed to, the following major seminars, workshops, symposia, conferences and congresses:

The 7th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2006) in Brisbane (Australia) 25-27 September 2006

The 25th International Modal Analysis Conference (IMAC XXV) in Orlando FL (USA) 19-22 February 2007

The International Heavy Haul Association Specialist Technical Session (IHHA STS 2007) in Kiruna (Sweden) 11-13 June 2007

The International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN2007 under the auspices of IACM, IAEE,EASD, EAEE and ECCSM) in Rethymno/Crete (Greece) 13-16 June 2007

The 14th International Congress on Sound and Vibration (ICSV14) in Cairns (Australia) 9-12 July 2007

The 20th IAVSD (International Association for Vehicle System Dynamics) Symposium on Dynamics of Vehicles on Roads and Tracks in Berkeley CA (USA) 13-17 August 2007

The 9th International Workshop on Railway Noise (IWRN9) in Feldafing/Munich (Germany) 4-8 September 2007

The 3rd International Conference on Adaptive Modeling and Simulation (ADMOS2007) in Gothenburg (Sweden) 22-24 October 2007

The 20th Nordic Seminar on Computational Mechanics (NSCM-20) in Gothenburg (Sweden) 23-24 November 2007

The 26th International Modal Analysis Conference (IMAC XXVI) in Orlando FL (USA) 4-7 February 2008

The 15th Nordic Seminar on Railway Technology in Hook (Sweden) 22-23 May 2008

The 4th International Conference on Railway Condition Monitoring in Derby (UK) 18-20 June 2008

The 4th International ASRANet (Network for Integrating Structural Safety, Risk and Reliability) Colloquium in Athens (Greece) 25-27 June 2008

The 2nd ASA-EAA (Acoustical Society of America - European Acoustics Association) Joint Conference Acoustics '08 in Paris (France) 29 June – 4 July 2008

The 6th International Conference on Low Cycle Fatigue (LCF6) in Berlin (Germany) 8-12 September 2008

The IUTAM (International Union of Theoretical and Applied Mechanics) Symposium on Progress in the Theory and Numerics of Configurational Mechanics in Erlangen (Germany) 20-24 October 2008

The 17th International Conference on Wear of Materials (WOM2009) in Las Vegas NV (USA) 19-23 April 2009

The ECCOMAS (European Community on Computational Methods in Applied Sciences) International Symposium on Inverse Problems in Mechanics of Structures and Materials (IPM2009) in Rzeszów/Łańcut (Poland) 23-25 April 2009

The International Symposium on Speed-up, Safety and Service Technology for Railway and Maglev Systems (STECH 09) in Niigata (Japan) 16-19 June 2009

The 9th International Heavy Haul Conference (IHHA2009) in Shanghai (China) 22-24 June 2009

The 21st IAVSD (International Association for Vehicle System Dynamics) Symposium on Dynamics of Vehicles on Roads and Tracks in Stockholm (Sweden) 17-21 August 2009

The 8th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2009) in Florence (Italy) 15-18 September 2009

The status report that follows applies as of June 2009. 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 Teknik 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 almost MSEK 1 000. Areas of interest for Abetong, with its headquarters in Växjö, are the design and manufacture of railway sleepers fitted with fastenings and pads for rails. Of particular interest are tools that are useful in the identification of loads on sleepers installed in tracks and the structural analysis and design of sleepers for main lines and turnouts, and 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 at some 35 locations in 20 countries around the world.

Banverket (1995 and 1990)

Banverket (BV) is the Swedish infrastructure authority and manager and has around 6 600 employees. CHARMEC's partners at BV are the Operations Division and Expert Support Unit. Areas of interest are the design, construction and maintenance of all types of track structures for high availability and reliability. Of particular interest are the wear and corrugation of the railhead (calling for maintenance grinding) and the overall degradation of the track structure. Understanding and predicting the effect on the track of proposed higher train speeds and increased axle loads is particularly important. Also important is research into vibration, noise and safety. BV has overall responsibility for the railway sector in Sweden (both infrastructure and rolling stock, and underground systems and tramways).

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 2 000 work in Sweden. The office in Västerås is one of the main engineering hubs for the company division Mainline & Metros. 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 CHARMEC is the effects of wheel/rail interaction on ride dynamics, wheel wear, wheel damage and rolling noise. Also interesting are 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 also wants to increase its understanding of the interface between rolling stock and track infrastructure when requirements for low levels of ground vibrations and external noise are to 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 3 500, of whom 145 are located in Sweden. The main area of interest in the co-operation with CHARMEC is brake systems. New overall concepts are being developed for signal transfer along the train. The components for tread braking of freight trains are being investigated, and of particular interest is the interaction between brake block and wheel tread. New and better materials for the blocks are sought.

Green Cargo AB (2000)

This government-owned Swedish logistics company has its headquarters in Stockholm/Solna and employs roughly 3 000 people in over 100 locations throughout the Nordic region and Europe. Green Cargo operates around 420 locomotives and 6 800 freight wagons and normally covers 32 000 million gross tonne-km annually. Green Cargo has some 30 terminals and logistics centres and provides haulage distribution all the way to the customer. Goods are transported by rail freight wherever possible, and rail operations are complemented with road freight to the final destination. Services include warehousing (around 200 000 sqm) and advanced logistics solutions. Areas of interest in the co-operation with CHARMEC are braking performance and noise emission, and improved designs and materials for wheels and axles.

Interfleet Technology AB (1995 and 1992)

Interfleet Technology is one of the world's leading rail consultancies with around 550 employees across three continents. Clients include governments, administrations and companies, including manufacturers, contractors and operators, banks, investors and development agencies. Swedish Interfleet Technology AB is headquartered in Stockholm/Solna, has eight other offices in Sweden and employs around 130 people.

Lucchini Sweden AB (1995 and 1987)

Lucchini Sweden is a railway wheelset manufacturer in Surahammar with 50 years in the business. The company has 60 employees and is a fully-owned subsidiary of Lucchini RS in Italy, one of the major suppliers in the world of wheels and wheelsets for trains. Areas of interest for Lucchini Sweden 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 with its headquarters in Stockholm. The company's main activities are travel services under its own name, and contract rail services for regional and national transport authorities. The main customers are private/business travellers and commuters, a total of almost 115 000 people per year. The SJ Group has around 4 000 employees, of which on-train staff and train drivers are the largest groups. Investments during 2008 totalled MSEK 800. Current projects are new high-speed trains and the refurbishment of old passenger coaches. High traffic safety is a key component of SJ's vision. SJ expects that CHARMEC research projects will create increased understanding and a better platform for improving technical solutions and maintenance work for the rolling stock.

AB Storstockholms Lokaltrafik (2003)

Stockholm Public Transport (SL) has overall responsibility for public transport in Stockholm County (Stockholms Län) and offers attractive and accessible transport by rail and road. The company is owned by Stockholm County, and its board members are elected by the County Council. SL administrates the operation, maintenance and renewal of rolling stock and all fixed railway installations and real estate within the Greater Stockholm Area railway network. The systems cater for some 2.7 million passenger trips every day. On an ordinary weekday, approximately 700 000 people use SL's services. Through its business strategies, SL contributes to long-term sustainable development in the Stockholm region. CHARMEC's main partners are SL's track and rolling stock departments (under the joint name of SL Technology). 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 is the leading Scandinavian provider of maintenance services for railway freight wagons. The business concept is to offer a complete and cost-effective range of maintenance services and technical support, and supply all kinds of spare parts including wheelsets. SweMaint has eight workshops in Sweden, from Malmö in the south to Borlänge in the north, with a total of about 250 employees. The headquarters and main workshop with modern wheelset maintenance facilities are located in Gothenburg. 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 co-operation with CHARMEC are related to improved wheelset quality from a general point of view. Kockums Industrier AB, the Nordic region's sole 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 7 000 employees worldwide. For financial year 1 April 2008 – 31 March 2009, the sales of the voestalpine Group (including all four divisions) amounted to MEUR 11 600. voestalpine Bahnsysteme GmbH & CoKG 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 up to 120 m with head-special-hardened (hsh) premium rail quality. The company also owns rail rolling mill TSTG in Duisburg, Germany.

VAE GmbH, with its headquarters in Vienna, Austria, is the world leader in turnout technology for high speed, heavy haul, underground and light railways but is also a system provider for the switch area (drive locking and detecting systems for turnouts) and related products, such as hazard analysis equipment and monitoring systems. 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. VAE GmbH is the holding company for 41 manufacturing locations in five regions (Europe, America, Australia, Africa, and Asia). The Austrian factory is situated in Zeltweg.

In June-July-August 2009, Banverket and the partners in the Industrial Interests Group for Stage 5 have 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.

Through CHARMEC, Abetong has initiated a new doctoral project and a senior project that focusses on the important interaction between the sleeper and the underlying ballast. Being a project co-ordinator and belonging to a reference group has created added value. In a PhD project, Abetong was able to involve one of the company's European licensees, which benefitted both parties. A senior project enabled Abetong to engage both a leading supplier of a vital track component and one of the most well-reputed European railway administrations. This uncomplicated and fruitful form of co-operation would have been difficult to establish without the forum created by CHARMEC.

Abetong's participation in CHARMEC constantly provides us with better knowledge of the complex interaction between the full track structure and the running train. This knowledge is crucial for discussions with other track component suppliers or railway administrations. 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

CHARMEC research has helped Banverket 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 and its customers. For instance, the upgrading of the Iron Ore Line in northern Sweden from 25 to 30 tonne axle load, and other lines from 22.5 to 25 tonne axle load has led to an estimated annual saving in the order of MEUR 70 for the two companies – LKAB (iron ore) and Stora Enso (paper and forest products) – that use these lines for their freight. Other companies using Swedish railways have also saved money through this investment.

During CHARMEC's Stages 4 and 5, the development of new projects dealing with track switches (turnouts) has been an important step forward. Today, Banverket spends about MEUR 100 annually on track maintenance, with track switches accounting for a large share of these costs. The present co-operation between Banverket and CHARMEC on rail corrugation, etc in the INNOTRACK project of the EU Sixth Framework Programme continues this development. Other projects of interest to Banverket have dealt with alarm limits for out-of-round wheels, the improved design of insulating rail joints, and safeguarding against rail breaks and track buckling (sun-kinks). Several projects have resulted in new specifications and new designs for concrete sleepers carrying up to 35 tonne axle load. CHARMEC has played an important role in co-ordinating Banverket's noise reduction projects and integrating them with other European projects to achieve synergy and increase efficiency.

Bombardier Transportation Sweden

One reason for joining CHARMEC in 2000 was that our subsidiary Adtranz Wheelset, through which we previously had access to CHARMEC's research results, was sold to the Lucchini Group. The wheelset research projects dealing with rolling contact fatigue, damage and cracks have been essential for understanding the behaviour of wheels in revenue traffic. The company recently initiated a new CHARMEC project on wheels and rails for train speeds 250 km/h that apply for Swedish conditions with mixed traffic and a harsh climate. CHARMEC's work with railway noise is also significant for the development of quieter trains. Our ambitions for improving the vibrational and acoustic behaviour of trains are reflected by the fact that Bombardier has also initiated new CHARMEC projects in this area. The company believes that the results will lead to the development of new systems and components for bogies and car bodies.

Faiveley Transport Nordic

The ongoing renewal of braking systems for railway freight wagons is driven by the need for higher train speeds, increased axle loads and lower noise levels. Faiveley Transport is now developing a new generation of block braking equipment for the world market. A broad approach combining theoretical models and results from rig and field tests has been initiated by CHARMEC. The block braking of freight and passenger wagons should be optimized with regard to high braking power together with low damage, low wear and low noise from the wheels. CHARMEC's involvement in the earlier EU project Euro Rolling Silently (ERS) has been of great value to the company. Faiveley Transport is also introducing modern computerized control systems for the braking of all kinds of locomotives, wagons and coaches. The correspond-

ing CHARMEC project addressed the extremely high level of safety and security that is required for these systems.

Green Cargo

The co-operation with CHARMEC has been important for evaluating existing wheelsets and approving new wheelset designs, particularly in regard to safety aspects such as crack propagation and safety margins. The Centre's researchers have actively developed the new wheelset designs for 25 and 30 tonne axle loads that are now used by Green Cargo. CHARMEC researchers have also co-operated with the company in the testing and evaluation of new composition brake blocks for low-noise freight transport. Green Cargo considers CHARMEC's competence in various aspects of wheel maintenance as an important asset.

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, brake systems, etc, which have all 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 over recent years has been the development of new freight wagon wheelsets for 25 and 30 tonne axle loads that are 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 at Surahammar, developed earlier together with Chalmers, has been extremely important in this work. The new wheel for 25 tonne axle load has been approved by UIC and the design is now patented. The wheelset has also been approved according to Technical Specifications for Interoperability (TSI). The CHARMEC work on out-of-round wheels has been invaluable in our efforts to improve production techniques. CHARMEC personnel have assisted Lucchini with technical developments and design calculations, the documentation and marketing of our products, and technical meetings with customers.

SJ

SJ AB became a member of CHARMEC during Stage 5 and has mainly benefitted so far from general information, semi-annual reports and the contacts provided by CHARMEC. Regarding 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 6, 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 new owner Kockums Industrier, with an information hub and research environment - and a speaking partner for technical issues that are important to the company. The MU projects have been particularly interesting because they relate to wheelset performance. CHARMEC has assisted SweMaint and Kockums Industrier with studies to improve the reliability of wheels and axles, and by discussing technical improvements. CHARMEC has also provided Kockums Industrier with TSI-approved wheelsets via Lucchini Sweden.

voestalpine Bahnsysteme

Understanding the mechanisms of crack initiation and crack growth in rails caused by wheel/rail contact is vital for voestalpine Schienen. During Stage 5, the co-operation with CHARMEC has focussed on simulation models for the early growth of small cracks, and the prediction of crack propagation directions. Material properties have also been studied. In Stage 6, the results of Stage 5 will be used to further develop crack growth models and study the interaction of rolling contact fatigue (RCF) and wear. The activity on material properties and material anisotropy of used rails and the influence on RCF will be further promoted. 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 have been tested in Stage 5. 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. The results will support the further development of suitable materials for crossings.

BJÖRN PAULSSON IN THE CHAIR 1995 – 2008

As mentioned on page 8, Banverket's Björn Paulsson resigned as member and chairman of CHARMEC's Board on 31 December 2008. To acknowledge his eminent achievements since CHARMEC started on 1 July 1995, a party was held on 18 February 2009 in Chalmersska Huset (the Chalmers House) at Södra Hamngatan 11 in Gothenburg. Current and previous Board members, and special guests from VINNOVA and Chalmers University, were invited.

William Chalmers (1748-1811), who bequeathed a large sum of money to the school, started in 1829, that later became the Chalmers University of Technology, built the house in 1805-1807 and lived there until his death. Both the exterior and interiors of the house have been preserved. Swedish bank SEB owned and used the house for a long time but donated it to Chalmers University in 2006. CHARMEC held its first Board Meeting in Chalmersska Huset on 19 February 2009, led by the new Chairman Tomas Ramstedt.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Celebration of Björn Paulsson and acknowledgement of his achievements in Chalmersska Huset on 18 February 2009

1 William Chalmers stayed 1783–93 in Canton and Macao as "resident supercargo" of the Swedish East India Company
2 Chalmersska Huset at Södra Hamngatan 11 in Gothenburg designed by city architect Carl Wilhelm Carlberg
3 Drawing-room in Chalmersska Huset (facing the East India House on the opposite side of the canal)
4 Bengt Åkesson delivers brief information on William Chalmers and his House
5 At the dinner table with Johan Oscarsson, Lennart Nordhall and Tomas Ramstedt on the left
6 Stefan Westberg and Bengt Åkesson
7 Roger Lundén and Staffan Hjorth (formerly Staffan Hjorth administered the NUTEK and VINNOVA competence centres)
8 Stefan Östlund and Roger Lundén
9 Roger Johansson (formerly responsible for the NUTEK/VINNOVA competence centres at Chalmers University)
10 Björn Paulsson with an 18th century Canton painting on the wall
11 Jens Nielsen and Mikael Fermér who earned the first two doctorates in railway mechanics at Chalmers University in 1993
12 Roger Johansson and Henrik Tengstrand

Some of the events and achievements during Stage 5 that have not been reported elsewhere are presented here.

Board Meetings relocated

Six of the twelve meetings of the CHARMEC Board during Stage 5 were combined with visits to organizations outside Chalmers: to voestalpine Schienen in Leoben and VAE in Zeltweg (Austria) on 12-13 September 2006; to Interfleet Technology in Stockholm/Solna on 29 May 2007; to SP Technical Research Institute of Sweden in Borås on 3 December 2007; to UIC in Paris (France) on 29-30 May 2008; to SL Technology in Stockholm on 9 December 2008, and to Kockums Industrier in Malmö on 28 May 2009.

Johan Oscarsson of SL Technology at the Board Meeting in Stockholm on 9 December 2008

VINNOVA

The NUTEK/VINNOVA funding of CHARMEC (total of KSEK 52 925) ceased during Stage 4. A final report from CHARMEC on the centre's overall activities 1 July 1995 – 30 June 2006 was submitted to VINNOVA on 13 April 2007 (17 pages plus 6 appendices). Required Key Numbers describe Co-operating Parties, Organization, Development, Financing/Economy, Scientific Results, and Industrial Effects.

Separate applications to VINNOVA from research groups at CHARMEC have been granted, see projects TS11, VB10 and MU18.

Banverket's engagement in CHARMEC

As part of Banverket's sectoral responsibility for the Swedish railways, this government authority appropriates a basic contribution for CHARMEC's research and for the centre's training and examination of PhDs in railway mechanics, see page 80. To motivate Banverket's contribution during Stage 6, CHARMEC submitted two documents (in Swedish) dated 2008-06-18 (9 pages plus 5 appendices) and 2008-11-05 (11 pages plus 4 appendices). The latter document responds to 20 specific questions from Banverket through Vägverket Konsult. For Banverket's general role in CHARMEC, see page 7.

KTH

Roger Lundén continues to serve on the Advisory Board for SAMBA projects at KTH Railway Technology. Several of CHARMEC's doctoral students have taken overview courses in railway technology at KTH (The Royal Institute of Technology in Stockholm). Collaboration also takes place between research groups at KTH and Chalmers, such as in projects MU20 and MU22. As already mentioned, Professor Stefan Östlund, Director of the KTH Railway Group, has served on the Board of CHARMEC. As of 1 July 2009, he has been replaced by Professor Mats Berg from the same body.

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, 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) 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.

Chair in Railway Mechanics

As of 1 June 2007, a Chair in Railway Mechanics was established at Chalmers University of Technology and CHARMEC's Director Roger Lundén was appointed first holder. The three experts reviewing his scientific qualifications were Professor Dudley Roach from the Cooperative Research Centre (CRC) for Railway Engineering and Technologies in Australia, Professor Roderick A Smith from Imperial College in London (UK) and Professor Niels Saabye Ottosen from Lund University (Sweden). On 16 November 2007, Roger Lundén delivered his "inauguration lecture" on Railway Mechanics.

Appointment of Docent

After an expert review of her academic achievements and a "docent lecture" to demonstrate her pedagogic qualifications, Dr Elena Kabo was awarded the degree of Docent on 2008-12-15. The reviewing experts were Professor Stefano Bruni from Politecnico di Milano (Italy) and Professor Sergey Zakharov from the All Russian Railway Institute in Moscow (Russia). The title of Elena Kabo's lecture was "På spåret: Kontakten hjul-räl och några andra järnvägsmekaniska problem" (On the track: Wheel-rail contact and some other aspects of railway mechanics). Elena Kabo earned her doctorate at Saint Petersburg State Technical University in Russia in 1998.

Editorial Board of JRRT

Since 2005, Professor Simon Iwnicki from Manchester Metropolitan University (MMU) in the UK has been Editor-in-Chief of 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 35 articles up to September 2009). IMechE stands for the Institution of Mechanical Engineers. Roger Lundén took part in Editorial Board Meetings on 2007-07-16 and 2008-02-21 at the IMechE premises in Westminster, London (UK).

Editorial Board of FFEMS

Since January 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.

Front cover of Special Issue of Wear October 2008

CM2009 and CM2006

The 8th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2009) is being held in Florence (Italy) on 15-18 September 2009 under the chairmanship of Professor Andrea Bracciali, University of Florence. As a result of their work during Stage 5, CHARMEC's researchers will be represented through ten contributions from projects TS13, VB10, MU16, MU18, MU20, MU22, MU23, MU24, EU10 and SP11, all of which have been accepted for oral presentations. CHARMEC's Roger Lundén serves on the International Committee for CM2009.

Selected papers from the previous conference CM2006 in Brisbane (Australia) on 25-27 September 2006 have been printed in a Special Issue of Wear (vol 265, nos 9-10, October 2008). CHARMEC researchers contributed to five of these papers.

Heavy haul

CHARMEC assists mining company LKAB and its subsidiary MTAB in Kiruna (Sweden) by solving problems with braking performance and wheel wear on their new iron ore wagons and locomotives, see project MU9. CHARMEC is a member of the local organization NHH (Nordic Heavy Haul), which in turn is a member of IHHA (International Heavy Haul Association). LKAB's Thomas Nordmark is Chairman and Roger Lundén is a member of the NHH Board.

On 11-13 June 2007, NHH arranged IHHA STS 2007 (Special Technical Session), also called IHHA2007, in Kiruna where CHARMEC contributed two papers, see projects MU18 and MU22. Eleven reviewed papers from IHHA2007 were published in a Special Issue of IMechE Journal of Rail and Rapid Transit (vol 223, no F2, March 2009) on High Tech

in Heavy Haul with a Guest Editorial written by Robert Fröhling, Per-Olof Larsson-Kråik, Roger Lundén and Thomas Nordmark.

In Kiruna on 8-10 June 2007, before IHHA2007, a Wheel Rail Interaction Course was held with about 40 participants, including doctoral candidates from CHARMEC's projects TS11 and MU18.

CHARMEC researchers also took part in the 9th IHHA Conference on 22-24 June 2009 in Shanghai (China) and presented three papers, see projects MU21, EU10 and SP1.

Front cover of Special Issue of JRRT March 2009

Contact mechanics course

A graduate course on contact mechanics was given at Chalmers University by Professor Roger Lundén, together with Docent Anders Ekberg, during January to April 2007. Five of CHARMEC's doctoral students took part. Rolling contact stresses, shakedown effects, material fatigue, sliding wear and fretting phenomena were some of the topics treated.

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".

Swedish Mechanics Days

A two-day conference titled "Svenska Mekanikdagar" (Swedish Mechanics Days) is arranged every second year and normally circulates between Swedish universities and institutes of technology. The latest conference in June 2009, however, was hosted by the company Scania AB in Södertälje, Sweden. Several of CHARMEC's researchers have presented their results at the conferences. These contributions are not listed under the CHARMEC projects.

Swedish Rail Forum

CHARMEC has been a member of the Swedish non-profit association Järnvägsforum (Rail Forum). It was launched in December 2002 and brought together organizations with an interest in promoting railways as an efficient, safe and environmentally friendly method of transportation. As of February 2008, Rail Forum transferred its activities to Swedtrain (Swedish Society of Railway Industries).

On 11 December 2006, Rail Forum arranged a seminar in Gothenburg with around 100 participants on "Järnvägens framtid och samhällsnytta" (Future and society benefits of railways). CHARMEC's Roger Lundén and Bengt Åkesson took part.

Damage tolerance of railway axles

On 13-14 October 2008, CHARMEC's Roger Lundén and Tore Vernersson were among about 70 participants (20 from academia and 50 from industry) who took part in an ESIS TC24 (see page 91) workshop with the above title at Politecnico di Milano (Italy). Crack growth rate, residual life and inspection intervals for railway axles were discussed.

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 now (since 2004) 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 focussing on safety, reliability and economic efficiency". The association's activities include "the definition, adaptation and implementation of advanced technology". During Stage 5, Roger Lundén continued to serve on ERWA's Technical Committee and took part in several meetings, usually at UNIFE in Brussels (Belgium). The 9th Annual Meeting on 11-13 May 2009 was hosted by Radsatzfabrik Ilsenburg, however, in Wernigerode (Germany).

ERWA now has assumed overall responsibility for the International Wheelset Congresses (IWC) beginning with the 15th IWC in Prague (the Czech Republic) on 23-27 September 2007 where CHARMEC's Roger Lundén and Bengt Åkesson took part. The 16th IWC will be held on 14-19 March 2010 in Cape Town (South Africa). Roger Lundén serves on the Technical Committee for IWC16.

Nordic Rail Fair

CHARMEC took part in the 7th Nordic Rail trade fair at the Elmia Exhibition Centre in Jönköping (Sweden) on 9-11 October 2007. We shared a stand with KTH Railway Group, VINNOVA and the Swedish National Road and Transport Research Institute (VTI). Our research projects were displayed on wall plates, three seminars were held (not listed under the CHARMEC projects) and printed material was distributed. A computer-generated rolling display on a monitor provided an overview of CHARMEC's work based on the previous Triennial Report. Several valuable contacts with the railway industry were (re)established at Nordic Rail. CHARMEC will take part in the 8th Nordic Rail trade fair at Elmia on 6-8 October 2009.

15th Nordic Seminar on railway technology

On 22-23 May 2008, CHARMEC arranged this seminar at Hooks Herrgård south of Jönköping (Sweden) with 115 participants and 47 presentations. Seven of these were Plenary Lectures held by Evert Andersson (Green Train), Mats Berg (Training in Railway Technology), Ulla Espling and Anders Ekberg (INNOTRACK), Anders Frid (Noise Reduction), Tomas Ramstedt (Research/Development/Demonstration), Stefan Sollander (TSI) and Marcin Tubylewics (Operator's Challenges). Summaries (most of them in Swedish) of all presentations are available on www.chalmers.se/charmec.

In a special Plenary Lecture followed by an animated discussion in the lecture hall and at the seminar dinner, Docent Jan Jörnmark of Chalmers University and Gothenburg University discussed modern technical developments and the digital revolution.

Fatigue and damage tolerance of railway rails

Within the European Structural Integrity Society (ESIS) there is a Technical Committee TC24: Integrity of Railway Structures. CHARMEC's Lennart Josefson and Roger Lundén have taken part in TC24 meetings. Roger Lundén delivered two lectures at a workshop in Paris (France) on 10-11 May 2007 with the above title for about 35 participants. Several contributions to that workshop will be printed in a Special Issue of the periodical Engineering Fracture Mechanics edited by Uwe Zerbst of GKSS Research Centre in Geesthacht (Schleswig-Holstein), Germany. One result of the workshop is the following article.

> Uwe Zerbst, Roger Lundén, Karl-Otto Edel and Roderick Smith: Introduction to the damage tolerance behaviour of railway rails, 60 pp (to be published in a Special Issue of *Engineering Fracture Mechanics*)

SVR Days

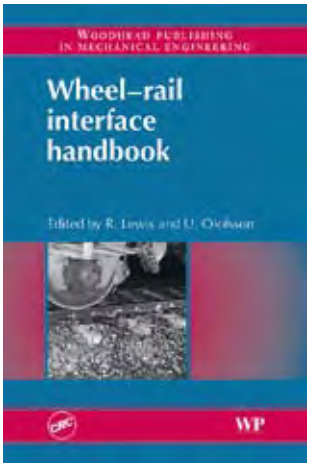
The Swedish Society of Civil and Structural Engineers (SVR) held its annual two-day conference in Gothenburg on 25-26 September 2008. The central theme this time was roads and railways, and the importance of this infrastructure for regional enlargement in western Sweden (Västra Götalandsregionen). CHARMEC's Bengt Åkesson took part. The second day involved a study trip along the Göta River (Göta Älv) valley where Banverket and Vägverket (the Swedish Road Administration) now are constructing a double-track railway and four-lane motorway from Gothenburg to Trollhättan. All of Sweden's installing capacity for lime-cement columns during two years is here being made use of in the deep clay layers close to the river.

Hooks Herrgård (Hook´s Manor House)

Wheel-rail interface handbook

This upcoming handbook from Woodhead Publishing Ltd in Cambridge (UK) is being edited by Roger Lewis (University of Sheffield, UK) and Ulf Olofsson (Royal Institute of Technology, Sweden). The book is said to be "a one-stop reference for railway engineering practitioners and academic researchers". Part 1 of the book deals with "State-of-the-art research" and Part 2 with "Industrial context – managing the wheel-rail interface". CHARMEC researchers were invited to contribute as follows:

Roger Lundén and Björn Paulsson: Introduction to wheel-rail interface research, pp 3-33
Anders Ekberg: Fatigue of railway wheels, pp 215-244
Jens Nielsen: Out-of-round railway wheels, pp 245-279



Cover image of Wheel-rail interface handbook

Delft University of Technology

CHARMEC's Roger Lundén took part in the promoting commission at Ivan Shetsov's defence in public of his doctoral dissertation "Wheel-rail interface optimisation" in Delft (the Netherlands) on 3 June 2008. On 5 June 2008, Roger Lundén held the same role for Michaël Steenbergen's doctoral dissertation "Wheel-rail interaction at short-wave irregularities" at the same place.

Roger Lundén with ceremonial gown and cap in Delft on 3 June 2008

Alstom Transport

The French company Alstom Transport, with Swedish headquarters in Stockholm and a maintenance workshop in Västerås, has approached CHARMEC on several occasions to discuss possible future collaboration. In Sweden, Alstom has delivered the Arlanda Express, double decker X40 (Coradia Duplex) and commuter train X60 (Coradia Lirex). No collaboration between Alstom Transport and CHARMEC has been established so far.

Stefan Westberg and Lennart Nordhall

As mentioned earlier, Stefan Westberg and Lennart Nordhall have been members of CHARMEC's Board since the centre started on 1 July 1995. Stefan Westberg resigned on 30 June 2008 and his achievements were acknowledged at a dinner in Paris (France) on 29 May 2008. Lennart Nordhall's services to CHARMEC were acknowledged at a dinner in Gothenburg on 31 March 2009. He stepped down from the Board on 30 June 2009.

Abetong's new sleeper production

On 2008-04-17, CHARMEC was invited to a combined study visit and inauguration of Abetong's sleeper production plant at Vislanda (Sweden) and Roger Lundén took part. Abetong has delivered a total of 8.5 million concrete sleepers to the Swedish railways and more than 60 million concrete sleepers have been produced worldwide by Abetong's 35 licensees across five continents. The new production of sleepers for 35 tonne axle load was demonstrated, see projects SP9 and SP12.

Green Train Programme

An initiative by Banverket and Bombardier Transportation Sweden – the Green Train (Gröna Tåget) Programme – was launched in 2005 and is planned to run until 2011. A successor to the Swedish high-speed train X2 is being developed through collaboration between Banverket, Bombardier Transportation, SJ AB, Interfleet Technology, KTH Railway Group, CHARMEC, VTI and others. The new train should have a maximum speed of 250 km/h (X2 has 200 km/h) on a conventional Swedish track with mixed traffic in a harsh climate. On future high-speed lines, the maximum speed should be 300 km/h. Track-friendly bogies, high ride comfort and low internal and external noise levels are required. During Stage 5, CHARMEC projects SP10 and SP11 have had a bearing on the Green Train Programme.

TSI

Technical Specifications for Interoperability (TSI) are being introduced by the European Committee for Standardization (Comité Européen de Normalisation, CEN) for railway infrastructure and rolling stock. CHARMEC's researchers have assisted the centre's industrial partners with TSI requirements for their products. Roger Lundén took part in a "Wagon TSI Seminar" at UNIFE in Brussels on 2008-11-20 where improved TSI according to Directive 2008/57/EC were discussed. The European Railway Agency (ERA) was represented at the seminar.

Sustainable and effective transport

In this area Chalmers University plan seek external funding for a research school for a proposed 100 doctoral students over a 10-year period. The local funding for one student plus a part-time senior adviser and researcher is calculated to be KSEK 1000 per year for a period of five years. CHARMEC has contributed with a document (in Swedish) containing 25 project proposals related to railway mechanics (15 pages, dated 2008-12-15). Several of these proposals are divided into two parts with one doctoral student from each of two departments, e g, Applied Mechanics and Mathematical Sciences.

Sustainable and safe transport systems

Worth mentioning here is "Sustainable and safe transport systems", one of 24 strategic research areas in the Research and Innovation Bill that the Swedish Government presented to Parliament in spring 2009 for the period 2009-2012. The proposed allocation for the 24 areas is MSEK 1800.

KVVS

CHARMEC's Roger Lundén was elected member of KVVS at a meeting on 8 December 2008. KVVS stands for Kungliga Vetenskaps- och Vitterhets-Samhället i Göteborg (The Royal Society of Arts and Sciences in Gothenburg). The society was founded in 1778 by King Gustav III of Sweden (1772-1792). Roger Lundén is one of ten members under the age of 65 in the society's Class 1 for Mathematical and Technical Sciences.

VR

Vetenskapsrådet

An application by three CHARMEC researchers to Vetenskapsrådet (The Swedish Research Council) has been approved, see project MU25. Vetenskapsrådet (VR) is a "government agency that provides funding for basic research of the highest scientific quality".

INNOTRACK technical reviews

Apart from contracted assignments in the European project INNOTRACK, see EU10 on page 65, CHARMEC researchers also contribute to the project by making technical reviews of deliverables submitted by organizations outside Chalmers University. Our Anders Ekberg co-ordinates this activity.

EU projects

The EU Seventh Framework Programme (FP7) will run 2007-2013 with a total budget of GEUR 50.5, of which GEUR 4.2 will be allocated to transport research (rail, road, sea, air). Chalmers/CHARMEC has been invited to take part in new Seventh Framework Programme projects in railway me-

On 14 September 2008, Bombardier's Regina Green Train (no 9062) set a Swedish speed record of 303 km/h on the Western Main Line between Skövde and Töreboda (otherwise used for 160-200 km/h)

chanics. None of the applications have been approved so far. Our extensive work in the EU project INNOTRACK, see again EU10, will end on 31 December 2009. Our contribution to the EU project QCITY is listed as project EU11, see page 67.

Publishing and other awards

Per Heintz from project MU12 received the "ECCOMAS Award for best PhD thesis in the computational field 2006". ECCOMAS stands for the European Community on Computational Methods in Applied Sciences.

At the IHHA Conference in Kiruna on 11-13 June 2007, see page 89, the contribution by Andrea Gianni, Andrea Ghidini, Tord Karlsson and Anders Ekberg, see project MU22, received one of three "Award Best Paper".

Exchange with voestalpine Bahnsysteme

As previously, meetings between CHARMEC researchers and their Austrian colleagues have been held twice a year during Stage 5 at rail manufacturer voestalpine Schienen in Leoben and switch manufacturer VAE in Zeltweg. Experts have also been invited to these two-day meetings from the University of Leoben (Institute of Mechanics), the Austrian Academy of Sciences (Erich Schmidt Institute of Materials Science), the Materials Centre Leoben and the Christian Doppler Laboratory (CDL) in Leoben. The dates and venues during Stage 5 were 18-19 January 2007 in Leoben and Zeltweg, 18-19 June 2007 in Leoben and Zeltweg, 12-13 December 2007 in Gothenburg, 16-17 June 2008 in Leoben and Zeltweg, 11-12 December 2008 in Gothenburg, and 2-3 June 2009 in Leoben and Zeltweg.

Monash University in Melbourne

In December 2006, Roger Lundén (assisted by Anders Ekberg and Bengt Åkesson) performed an external evaluation of the Institute of Railway Technology (IRT) at Monash University in Melbourne (Australia) regarding their "research quality".

SBB and ÖBB

As mentioned under project TS10, several contacts have been made with Schweizerische BundesBahnen (SBB) and the producer of Under Sleeper Pads (USP), Getzner Werkstoffe GmbH in Bludenz/Bürs (Austria). A contract has been signed with Getzner Werkstoffe through its agency Christian Berner AB in Gothenburg. Discussions have also been held with Österreichische BundesBahnen (ÖBB).

Special investigations

CHARMEC's senior researchers have assisted Interfleet Technology, Lucchini Sweden, SJ, SweMaint, Green Cargo and others with various special investigations (in addition to the work that has been listed for our projects).

CHARMEC's visit to voestalpine's wheel/rail rolling test rig in Leoben/ Donawitz in June 2009

External consultants and employees

Including CHARMEC's EU projects in the regular programme of studies and research has only been partly possible for PhD students. Senior researchers have also been required to contribute to other projects at short notice. Chalmers/CHARMEC consequently engaged Dr Anders Johansson of Epsilon HighTech AB as an external part-time consultant during Stage 5. Professor Jens Nielsen, Docent Elena Kabo and Dr Tore Vernersson from the same consultancy have carried out research and supervision for CHARMEC on a full-time basis. Docent Anders Ekberg has been employed at Chalmers Industriteknik (CIT) since April 2005, but continued to work full-time for CHARMEC.

Guests

Visitors to CHARMEC during Stage 5 have included Maksym Gladskyi from Kiev Polytechnic Institute in Ukraine (November 2006), Yoshiaki Terumichi from Sophia University in Japan (March 2007), Takanori Kato from the wheel manufacturer Sumitomo Metal Industries in Japan (October 2007), James McCastlin and Pelle Duong from the sleeper manufacturer CXT Concrete Ties (within the LB Foster Company) in the United States (November 2008), Christopher Barkan from the Railroad Engineering Program at University of Illinois at Urbana-Champaign in the United States (February 2009), and Toru Miyauchi from the Railway Technical Research Institute in Japan and UIC (June 2009).

Associated projects

Since October 2005, railway-related research projects at the Division of Fluid Dynamics (part of the Department of Applied Mechanics) at Chalmers University have been connected to CHARMEC as Associated Projects (AP). Researchers who run the projects are invited to CHARMEC's seminars. Before the Board Meeting on 2008-02-04, Docent Siniša Krajnović of the above division held a seminar titled "Influence of wind gusts on high-speed trains".

Miscellaneous

During Stage 5, CHARMEC's personnel took part in several meetings and other events not included above. They were involved in workshops with Banverket and members of the Industrial Interests Group, minor seminars with research colleagues, invited presentations at various arrangements in Sweden and abroad, etc. All of these events and achievements indicate the high demand for CHARMEC's knowledge and services.

FINANCIAL REPORT

This is a presentation of the cash and in-kind investments for Stage 5, 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, the Industrial Interests Group and Chalmers have been calculated according to the principles stated in the Principal Agreement for Stage 5 dated 16 July 2006.

Report per party

Budgeted cash and in-kind investments per party according to the Principal Agreement for Stage 5 are presented in Table 1. Included are also cash contributions from Chalmers, Banverket, the Industrial Interests Group, VINNOVA and UIC that were not included in the Principal Agreement for Stage 5. Cash contributions from the EU are also included although they are not a formal part of CHARMEC's budget.

Cash investments

A letter dated 12 October 2006 from CHARMEC to each of the following: Banverket, Abetong Teknik AB, Bombardier Transportation Sweden AB, Faiveley Transport Malmö AB, Interfleet Technology AB, Lucchini Sweden AB, SJ AB, AB Storstockholms Lokaltrafik (SL) and voestalpine Bahnsysteme GmbH, proposed how the payments from the partners to CHARMEC should be settled. According to the letter, CHARMEC would invoice on six different occasions: 2006-10-01, 2007-03-01, 2007-09-01, 2008-03-01, 2008-09-01 and 2009-03-01. This proposal was accepted by all partners.

Agreements were reached between CHARMEC and Green Cargo AB in September-November 2006, and between CHARMEC and SweMaint AB in September-October 2006 concerning partnership during Stage 5. According to these agreements, CHARMEC would invoice Green Cargo AB and SweMaint AB on the six dates specified above.

In spring 2004, Banverket decided to continue contributing 50 % of the funding required for the TS7 and MU14 projects, i e, KSEK 350 for each of the two projects during Stage 4 and KSEK 350 for each of the two projects during Stage 5. According to agreements reached in September 2005, CHARMEC would invoice Banverket KSEK 100 + 100 and KSEK 250 + 250 respectively, on 2006-09-01 and 2007-03-01.

An agreement was reached in March-April 2004 between CHARMEC and Banverket concerning the VB9 project "Dynamics of railway systems" where Banverket's contribution was KSEK 1800 during Stage 4 and KSEK 900 during Stage 5. According to an agreement in October 2004, CHARMEC would invoice Banverket KSEK 450 on 2006-09-01 and 2007-03-01.

In January 2005, Banverket approved a project proposal from Interfleet Technology with a budget totalling KSEK 1650, of which KSEK 800 were assigned to the CHARMEC SP11 project "Vertical contact forces of high-speed trains", with KSEK 365 for Stage 4 and KSEK 435 for Stage 5.

In January 2006, VINNOVA approved two project proposals from CHARMEC providing 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 will be paid during Stage 6.

In August 2006, the EU approved a project proposal from Chalmers/CHARMEC and our European partners providing KSEK 5 096 to the EU10 project "INNOTRACK".

In September 2006, it was agreed that Banverket would contribute KSEK 230 to the TS9 project "Track dynamics and sleepers".

In October 2006, VINNOVA approved a project proposal from CHARMEC providing KSEK 300 to the EU10 project "INNOTRACK" for Anders Ekberg's work and expenses in his technical co-ordination of the overall project on the European level.

In October 2006, it was agreed that Banverket would contribute KSEK 200 to the TS10 project "Track response when using under sleeper pads (USP)", KSEK 200 to the SP8 project "Design of insulated joints", KSEK 300 to the SP10 project "Noise reduction measures and EU project QCITY" and KSEK 450 to the SP12 project "New sleeper specifications".

In November 2006, it was agreed that Banverket would contribute KSEK 300 to the SP13 project "Alarm limits for wheel damage".

In December 2006, Banverket approved a project proposal from IVL Svenska Miljöinstitutet (IVL Swedish Environmen-

Table 1. Cash and in-kind contributions (kSEK) per party during Stage 5

Party	Cash		In-kind		Total	
	Budget	Paid	Budget	Performed	Budget	Paid/Perf
Chalmers	11 001	11 001	13 500	13 500	24 501	24 501
Abetong	1 455	1 200	600	414	2 055	1 614
Banverket	18 383	17 444	1 350	1 740	19 733	19 184
Bombardier	2 250	2 100	900	1 250	3 150	3 350
Faiveley	1 350	1 350	600	439	1 950	1 789
Green Cargo	720	720	480	0	1 200	720
Interfleet	150	150	150	849	300	999
Lucchini	1 200	1 200	900	990	2 100	2 190
SJ	600	600	–	–	600	600
SL	1 200	1 200	300	231	1 500	1 431
SweMaint	600	600	300	0	900	600
voestalpine	1 950	1 950	2 550	3 035	4 500	4 985
VINNOVA	5 275	5 275	–	–	5 275	5 275
UIC	600	365	–	–	600	365
EU	5 596	2 772	–	–	5 596	2 772
From Stage 4	7	7	–	–	7	7
TOTAL	52 337	47 934	21 630	22 448	73 967	70 382

Note Remaining amounts KSEK 255 + 939 + 150 + 235 = KSEK 1579 from Abetong, Banverket, Bombardier Transportation Sweden and UIC, respectively, will be invoiced during autumn 2009. An additional KSEK 2824 is expected from EU. The EU funding does not formally belong to CHARMEC's budget

tal Research Institute) with a budget totalling kSEK 820, of which kSEK 100 were assigned to the CHARMEC SP14 project "Particle emissions and noise from railways".

In July 2007, it was agreed that UIC would contribute kSEK 300 to the EU10 project "INNOTRACK" for Anders Ekberg's co-ordination work, see above.

In November 2007, it was agreed that Banverket would contribute, in addition to the agreement of November 2006, see above, kSEK 220 to the SP13 project "Alarm limits for wheel damage".

In November 2007, it was agreed that Faiveley Transport would contribute kSEK 300 to the SP15 project "Computer program for design of block brakes".

In April 2008, it was agreed that Banverket would contribute kSEK 2 384 to the EU10 project "INNOTRACK" of which kSEK 2 084 is supplementary to the EU funding. The remaining kSEK 300 are for Anders Ekberg's co-ordination work, see above. According to the agreement, CHARMEC would invoice on four dates: 2008-05-15 (kSEK 900), 2008-09-01 (kSEK 500), 2009-03-01 (kSEK 500) and 2009-09-01 (kSEK 484).

In November-December 2008, it was agreed that Abetong would contribute kSEK 255 and Banverket kSEK 255 to the SP16 project "Identification of dynamic properties in track of timber sleepers and concrete replacement sleepers". In February 2009, it was agreed that Banverket would contribute kSEK 609 to the SP17 project "Switch sleeper specifications".

In February 2009, it was agreed that Banverket would contribute kSEK 300 and Bombardier Transportation Sweden kSEK 150 to the SP18 project "Ground vibrations from railway traffic – a prestudy on the influence of vehicle parameters".

In February 2009, it was agreed that UIC would contribute an additional kSEK 300 to the EU10 project "INNOTRACK" for Anders Ekberg's co-ordination work, see above.

In spring 2009, the INNOTRACK Consortium agreed to contribute another kSEK 500 of EU funding to the EU10 project "INNOTRACK".

Chalmers University of Technology supports CHARMEC financially. For Stage 5, the agreed amount was kSEK 3 000 from Chalmers centrally, kSEK 1 500 from the Department of Applied Mechanics, kSEK 1 800 from its Division of Dynamics, and kSEK 1 200 from its Division of Material and Computational Mechanics. The Department of Materials and Manufacturing Technology contributed kSEK 900. The Division of Technical Acoustics in the Department of Civil and Environmental Engineering contributed kSEK 300.

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.

Table 2. Budgeted and used cash and in-kind contributions (kSEK) during Stage 5, with the Industrial Interests Group (including Banverket) and Chalmers shown separately, for each programme area and for management and administration. CHARMEC's programme areas for Stage 5 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	8 075	7 647	2 550	2 802	2 100	2 100	12 725	12 549
VB	4 354	5 299	300	1 184	1 035	1 035	5 689	7 518
MU	13 196	11 342	3 400	3 194	2 910	2 910	19 506	17 446
SD	3 000	2 280	850	475	1 515	1 515	5 365	4 270
EU	10 331	8 706	–	–	1 800	1 800	12 131	10 506
SP	4 624	3 575	1 030	1 293	1 640	1 640	7 294	6 508
Management	3 900	3 875	–	–	2 500	2 500	6 400	6 375
TOTAL	47 480	42 724	8 130	8 948	13 500	13 500	69 110	65 172

Note 1 Budget under "Cash" is as of 28 May 2009 and may later be revised by the CHARMEC Board

Note 2 Bilateral contributions not included in the budget: Christian Berner/Getzner Werkstoffe kSEK 150 for TS10

Note 3 The balance in cash to be transferred to CHARMEC's Stage 6 by 30 June 2009 is kSEK 52337 – 47480 = kSEK 4857

Note 4 The amounts are incomplete for projects EU10, SP16, SP17 and SP18 which were not completed by 30 June 2009 but will still be referred to Stage 5

Chalmers also agreed to contribute KSEK 1 300 during Stage 5 to the SD6 project "Adaptronics for bogies and other railway components" from a donation. For Stage 5, Chalmers has also contributed KSEK 1 001 to the EU10 project "INNOTRACK".

The following amounts in cash, totalling KSEK 28 514, due for CHARMEC's Stage 5 have been received as per agreements:

6 × KSEK 200	Abetong Teknik
6 × KSEK 1 800	
+KSEK (350+350+450+450	
+435+230+200+200+300	
+450+300+100+220+900	
+500+500+255+304+150)	
= KSEK 17 444	Banverket
6 × KSEK 350	Bombardier Transportation Sweden
6 × KSEK 175 + KSEK 300	Faiveley Transport
6 × KSEK 120	Green Cargo
6 × KSEK 25	Interfleet Technology
6 × KSEK 200	Lucchini Sweden
6 × KSEK 100	SJ
6 × KSEK 200	SL
6 × KSEK 100	SweMaint
6 × KSEK 325	voestalpine Bahnsysteme

The following amounts in cash, totalling KSEK 1 344, due for CHARMEC's Stage 5 remain to be invoiced:

KSEK 255	Abetong Teknik
KSEK 484+305+150 = KSEK 939	Banverket
KSEK 150	Bombardier Transportation Sweden

From UIC, KSEK 365 in cash have been received and a further KSEK 235 will be invoiced for project EU10 (and referred to Stage 5).

From VINNOVA, KSEK 4 975 + 300 = KSEK 5 275 in cash have been received for projects VB10, MU18 and EU10.

From EU, KSEK 2772 in cash have been received for project EU10 and an additional KSEK 2824 is to be received.

Finally, KSEK 3 000 + 1 500 + 1 800 + 1 200 + 900 + 300 + 1 300 + 1 001 = KSEK 11 001 have been received from Chalmers University. The total amounts are shown in Table 1.

In-kind contributions

The in-kind contributions made by Banverket and the Industrial Interests Group correspond well to the agreement for Stage 5, 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.

MANAGEMENT AND ADMINISTRATION

Director	Professor Roger Lundén
Period	1997-04-01–2009-06-30 (–2012-06-30)
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 3 600
Industrial interests in-kind budget and results, see pages 14-79	–

Roger Lundén has devoted approximately half of his full-time position to the management and administration of the CHARMEC Competence Centre during Stage 5, and the rest of his time to duties as teacher, researcher and research supervisor in Applied Mechanics. Bengt Åkesson, Professor Emeritus of Solid Mechanics and Director of CHARMEC until April 1997, has assisted in the administration of CHARMEC together with Birgitta Johanson from Applied Mechanics. She has also served as the Centre's secretary. From Stage 3 Anders Ekberg has joined Bengt Åkesson and Birgitta Johanson in the administration of the Centre. All three are involved on a part-time basis.

CHARMEC STAGE 6

The Principal Agreement for CHARMEC's Stage 6 (1 July 2009 – 30 June 2012) complies with VINNOVA's Principal Agreement for the Centre's Stage 4. As with Stage 5, Banverket has been included directly in the agreement for Stage 6 and partly holds the administrative role that was previously filled by VINNOVA. The rights and obligations of the three parties (Chalmers University of Technology, Banverket and the Industrial Interests Group) comply with the Principal Agreements for Stages 4 and 5.

The programme areas in Stage 6 are the same as during Stage 5, see TS, VB, MU, SD, EU and SP on page 11.

Funding (KSEK) for Stage 6 (as of 28 May 2009) 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, Karin Markides, signed the contracts for Stage 6 on 9 June 2009. She appointed the following board members for CHARMEC's Stage 6 (decision dated 17 June 2009):

Tomas Ramstedt (chairman)	Banverket
Rikard Bolmsvik	Abetong
Henrik Tengstrand	Bombardier Transportation
Johan Mårtensson	Faiveley Transport
Marcin Tubylewics	Green Cargo
Hugo von Bahr	Interfleet Technology
Erik Kihlberg	Lucchini Sweden
Susanne Rymell	SJ
Johan Oscarsson	Storstockholms Lokaltrafik
Peter Linde	SweMaint
Håkan Anderson	voestalpine Bahnsysteme
Per Lövsund	Chalmers
Hans Andersson	Chalmers and SP Technical Research Institute of Sweden
Mats Berg	The Royal Institute of Technology (KTH)

For a photo of members of the new Board, see page 9

On 17 June 2009, Karin Markides also appointed Roger Lundén as Director of CHARMEC for Stage 6.

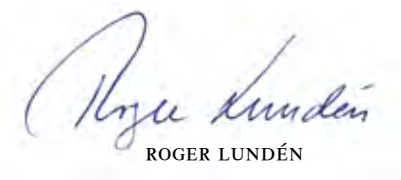
	Cash	In-kind	Total
Industrial Interests Group	10 800	6 690	17 490
Banverket (agreement)	12 000	1 500	13 500
VINNOVA (projects)	400	–	400
Chalmers	10 000	9 000	19 000
Chalmers (donation)	3 000	–	3 000
Chalmers (VR project)*	2 400	–	2 400
From Stage 5	4 857	–	4 857
TOTAL	43 457	17 190	60 647

* The funding from VR (The Swedish Research Council/Vetenskapsrådet) does not formally belong to CHARMEC's budget

CONCLUDING REMARKS

Stage 5 of the NUTEK/VINNOVA Competence Centre in Railway Mechanics has been successful. Co-operation between the university, industry and Banverket 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 6 with confidence. Our motto of "academic excellence combined with industrial relevance" will continue.

Gothenburg in September 2009



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 / Dr Johan Jonsson

TS (cont'd)

TS11 Rail corrugation growth on curves
Prof Jens Nielsen / Dr Anders Frid / Mr Peter Torstensson

TS12 Identification of wheel/rail contact forces
Doc Fredrik Larsson / Dr Håkan Johansson / Prof Kenneth Runesson / Dr Peter Möller / Prof Jens Nielsen / Mr Hamed Ronasi

TS13 Optimization of track switches
Prof Jens Nielsen / Prof Thomas Abrahamsson / Mr Björn Pålsson

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
Signals and Systems

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[3]
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
Prof Wolfgang Kropp / Ms Astrid Pieringer[1]

MU Materials and maintenance
Programme area 3

MU1 **Mechanical properties of ballast**
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**
Dr Johan Ahlström / Prof Birger Karlsson
Mr Niklas Köppen[1]

MU17 **Elastoplastic crack propagation in rails**
Dr Fredrik Larsson/Prof Kenneth Runesson /
Prof Lennart Josefson
Mr Johan Tillberg[1]

MU18 **Wheels and rails at high speeds and axle loads**
Doc Anders Ekberg / Prof Lennart Josefson /
Prof Kenneth Runesson / Prof Jacques de Maré
Mr Johan Sandström[1]

MU19 **Material anisotropy and RCF[6] of rails and switches**
Doc Magnus Ekh / Prof Kenneth Runesson /
Doc Anders Ekberg
Ms Nasim Larijani

MU20 **Wear impact on RCF[6] of rails**
Doc Magnus Ekh / Doc Fredrik Larsson /
Doc Anders Ekberg
Mr Jim Brouzoulis

MU (cont'd)

MU21 **Thermal impact on RCF[6] of wheels**
Doc Anders Ekberg / Doc Elena Kabo /
Doc Magnus Ekh / Dr Tore Vernersson
Ms Sara Caprioli

MU22 **Improved criterion for surface initiated RCF[6]**
Doc Anders Ekberg
Doc Elena Kabo / Prof Roger Lundén

MU23 **Material behaviour at rapid thermal processes**
Prof Birger Karlsson / Dr Johan Ahlström
Mr Krste Cvetkovski

MU24 **High-strength steels for railway rails**
Prof Birger Karlsson / Dr Johan Ahlström
Mr Martin Schilke

MU25 **Thermodynamically coupled contact between wheel and rail**
Doc Anders Ekberg / Doc Fredrik Larsson /
Prof Kenneth Runesson
Mr Andreas Draganis

Notes:
1. Licentiate (teknologie licentiat)
2. PhD (teknologie doktor)
3. This project has been finished
4. Now at Linköping Institute of Technology
5. Doctoral candidate to be recruited (none)
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 of 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**
Prof Viktor Berbyuk / Doc Mikael Enelund
Mr Albin Johnsson

SD7 **Thermal capacity of tread braked railway wheels**
Prof Roger Lundén / Dr Tore Vernersson
Mr Shahab Teimourimanesh

SD8 **Wear of disk brakes and block brakes**
Dr Tore Vernersson / Prof Roger Lundén

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**
Prof Roger Lundén
with some 20 co-workers

EU11 **QCITY**
Prof Jens Nielsen

SP Parallel special projects
Programme area 6

SP1 **Lucchini Sweden AB (bilateral agreement)**

SP2 **Noise from Swedish railways**

SP3 **Track force measurements on X2**

SP4 **VAE AG (bilateral agreement)**

SP5 **voestalpine Schienen GmbH (bilateral agreement)**

SP6 **Development of a quiet rail**

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**

CHALMERS FACTS 2009

DEPARTMENTS AND RESEARCH GROUPS/DIVISIONS/AREAS

APPLIED INFORMATION TECHNOLOGY
• Centre for Competence and Knowledge Building in Higher Education (CKK) • Centre of Visualisation Göteborg • IT and Innovation • IT Management • Learning, Communication and IT • Medical Informatics • Public Safety and Crisis Management • Software Engineering and Management

APPLIED MECHANICS
• Combustion • Dynamics • Fluid Dynamics • Material and Computational Mechanics • 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
• Architectural Applications • Architectural Tectonics • Innovative Design • Sustainable Development • Theory and History of Architecture

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• 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 and Biotechnology • Nuclear Chemistry • Organic Chemistry • Pharmaceutical Technology • Physical Chemistry • Polymer Technology • Systems Biology

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• Applied Acoustics • Building Technology • Construction Management • GeoEngineering • Structural Engineering • Water Environment Tech-nology

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RADIO AND SPACE SCIENCE
• Advanced Receiver Development • Global Environmental Measurements • 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)

SHIPPING AND MARINE TECHNOLOGY
• Ship Design • Ship Work Environment and Safety • Shipping Logistics and Chartering • Sustainable Ship Propulsion • Maritime Waypoint

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Engineering preparatory semester, 0.5 year (The Boost for Engineers)

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Computer Engineering
Electrical Engineering
Economics and Manufacturing Technology
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School of Continuing and Professional Studies
CIT(Chalmers Industriteknik)
Maritime Waypoint
The Boost for Teachers

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Railway

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Mechanics

CHARMEC

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