TRIENNIAL REPORT
1 July 2003–30 June 2006

REVIEW
1 July 1995–30 June 2003

PLANS
1 July 2006–30 June 2009

CHARMEC

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

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5. Doctoral candidate to be recruited
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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

FOREWORD

This is a report on the organization, operation and financing of Stage 4 of the NUTEK/VINNOVA Competence Centre CHARMEC. Summaries of the research performed at the Centre are presented. A review of Stages 1, 2 and 3 and a look ahead at Stage 5 are also included.

The fold-out on pages 3-4 contains an overview of all CHARMEC projects since the Centre started on 1 July 1995.

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

Gothenburg in December 2006

ROGER LUNDÉN
Director of CHARMEC

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

"How it all started in 1995". Associate Professors Tore Dahlberg (left) and Roger Lundén (middle) together with Professor Bengt Åkesson in the laboratory of Chalmers Solid Mechanics

Main entrance to Chalmers University of Technology with the Students 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 Stage 3. Two quotations from the conclusions drawn by the evaluators in March 2003* 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.

The Competence Centre *CHA*lmers *R*ailway *MEC*hanics was established in July 1995 at Chalmers University of Technology in Gothenburg, Sweden. Its annual budget during the three years of Stage 4 has been MSEK 24.5 (about MEUR 2.7), see page 90 in the following. Three parties have contributed to the financing: the University, VINNOVA, and an Industrial Interests Group, comprising ten partners, including the Swedish National Rail Administration, Banverket. In total, 29 ordinary research projects together with 4 EU projects and 6 development projects were run during Stage 4 within the six programme areas, see the fold-out on pages 3-4 and also on page 10 of the present report,

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

At Chalmers, 51 people (project leaders, academic supervisors, doctoral students and senior researchers) from 4 Departments (out of a total 16 at Chalmers) have been involved. They published 106 scientific papers in international journals and conference proceedings during Stage 4. Nine licentiate degrees and six PhD degrees were conferred during Stage 4. A total of 30 licentiate degrees and 23 PhD degrees in railway mechanics have been awarded to date (December 2006) at Chalmers, see page 76. There have been around 100 partners (industries, universities, institutes, public agencies, consultancies) from 19 countries involved in our four European projects during Stage 4.

CHARMEC is endeavouring to combine academic excellence and industrial relevance, generating first-rate research and able PhDs. Our work includes mathematical modelling, numerical studies, laboratory experiments and full-scale field measurements. There has been close cooperation with the Industrial Interests Group. Transfer of knowledge in both directions has taken place through advisory groups and industrial site visits, at regular seminars and brain-storming meetings and also through 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 Luchini Sweden plant site in Surahammar have been used. Activities will continue during Stage 5.

* The evaluators were the 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) as well as the specialists Dr Robert D Fröhling (Spoornet Engineering, RSA) and Professor Dudley Roach (Central Queeensland University, Australia). See VINNOVA's Information Report VI 2003:4.

Funding (MSEK) of CHARMEC during Stages 1 to 5, excluding EU projects. Note that Stage 1 only lasted two years whereas the following stages are for three years. The approximate exchange rate (December 2006) is 1 MEUR = 9 MSEK

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	38.3	20.8	59.1	48.5*	21.6*	70.1*

* After the Board meeting on 29 November 2006 and including cash funding of EU project INNOTRACK, see page 67

INTRODUCTION

CHARMEC is the acronym for *CHA*lmers *R*ailway *MEC*hanics. This Centre of Excellence, or Competence Centre, was established at Chalmers University of Technology in 1995. The formal agreement was reached at the Swedish National Board for Industrial and Technical Development (NUTEK) in Stockholm on 7 July 1995. Joint funding of 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 Abetong Teknik, Adtranz Wheelset, Banverket and SJ. Research in railway mechanics had started on a small scale at Chalmers Solid Mechanics back in 1987, when the first bilateral contract between Bengt Åkesson of that department and Åke Hassellöf of Sura Traction (later ABB Sura Traction and Adtranz Wheelset, and now Lucchini Sweden) was signed, see page 83.

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 and Inexa Profil then joined as new industrial partners.

The agreement on 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 seven 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).

The agreement on CHARMEC's Stage 4 (1 July 2003 – 30 June 2006) was reached at VINNOVA's office in Stockholm on 19 June 2003. SL Infrateknik (a subsidiary of Storstockholms Lokaltrafik / Stockholm Urban Transit Authority) and voestalpine Bahnsysteme (Austrian rail and switch manufacturer) joined as new industrial partners (SL Infrateknik had become involved on 1 January 2003). VINNOVA's MSEK 6.0 per annum was only paid during the first two years of Stage 4.

At the end of this report, a brief outline is given of CHARMEC's Stage 5, which runs from 1 July 2006 to 30 June 2009. The volume of CHARMEC's activities since its start is reflected in the table on page 6.

The three parties to the agreement on CHARMEC's Stage 4 were

Chalmers University of Technology

The Swedish Governmental Agency for Innovation Systems (VINNOVA)

The Industrial Interests Group:

Abetong Teknik – a HeidelbergCement Group company and concrete sleeper manufacturer with its headquarters in Växjö

Banverket – the Swedish National Rail Administration (the national authority with combined overall responsibility for the railway infrastructure and rolling stock) with its headquarters in Borlänge

Bombardier Transportation Sweden – a train manufacturer with its headquarters in Västerås

Duroc Rail – an engineering industry and development company with its headquarters in Luleå

Green Cargo – a railway freight operator with its headquarters in Stockholm/Solna

Lucchini Sweden – a wheelset manufacturer (the only one in the Nordic region) located in Surahammar

SAB WABCO Group (now *Faiveley Transport*) – an international manufacturer of braking systems with its Swedish headquarters in Malmö

SL Infrateknik (now *SL Technology*) – part of the regional railway administration SL (Storstockholms Lokaltrafik) in the Greater Stockholm area

TrainTech Engineering Sweden (now *Interfleet Technology*) – a consulting company with its headquarters in Stockholm/Solna

voestalpine Bahnsysteme – an Austrian manufacturer of rails and switches with its headquarters in Leoben

CHARMEC's youngest co-worker, Elisa Ekberg, 8 months, at the SP laboratory in Borås. The experimental set-up in project SP7 "Lateral track stability" is being studied in November 2006

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

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

BOARD AND DIRECTOR

Jan-Eric Sundgren, President of Chalmers University of Technology, in consultation with the Industrial Interests Group and VINNOVA, appointed the following as members of the Board of the Competence Centre CHARMEC during Stage 4 (decision dated 19 August 2003):

Björn Paulsson (chairman)	Banverket Headquarters
Stefan Westberg	Abetong Teknik
Henrik Tengstrand	Bombardier Transportation Sweden
Ulf Bergstedt	Duroc Rail
Lennart Nordhall	Lucchini Sweden
Roger Jönsson	SAB WABCO Group (now Faiveley Transport)
Håkan Tirus	SL Infrateknik (now SL Technology)
Hugo von Bahr	TrainTech Engineering Sweden (now Interfleet Technology) and Green Cargo
Håkan Anderson	voestalpine Bahnsysteme
Stefan Östlund	The Royal Institute of Technology (KTH)
Hans Andersson	SP Swedish National Testing and Research Institute (from 2007-01-01: SP Technical Research Institute of Sweden)

Professor Roger Lundén of Chalmers Solid 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.

The Board of CHARMEC at its meeting on 1 February 2006 ▶

Standing (from left)
Bengt Åkesson of Chalmers (initiator and former Director of CHARMEC)
Ulf Bergstedt of Duroc Rail (3+4)
Hans Andersson of SP Swedish Testing and Research Institute (1+2+3+4+5)
Stefan Westberg of Abetong Teknik (1+2+3+4+5)
Henrik Tengstrand of Bombardier Transportation Sweden (3+4+5)
Stefan Östlund of KTH (2+3+4+5)
Anders Ekberg of Chalmers (senior researcher)
Lennart Nordhall of Lucchini Sweden (1+2+3+4+5)

Seated (from left)
Birgitta Johanson (secretary)
Björn Paulsson of Banverket (Chairman, 1+2+3+4+5)
Roger Lundén of Chalmers (Director of CHARMEC)
Håkan Tirus of SL Technology (4+5)
Hugo von Bahr of Interfleet Technology (1+2+3+4+5)

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

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 such as CHARMEC should take the following points into consideration:

- The ability to understand, formulate and "make scientific" the current problems and aims of 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
- The transfer to 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 4, 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, as well as 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 the industrial partners, and during frequent visits, including brain-storming sessions etc, to the 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 industry has taken place by means of regular personal contacts and exchange of staff, through orientation and summarizing at seminars, and through informative reports and the handing over of test results and computer programs. An important aspect of this transfer of knowledge is the employment in the industry, directly or through consulting companies, of persons who have been awarded a degree as Licentiate or PhD at the University.

Each individual research project within the Centre should normally correspond to the five-year work for a doctoral dissertation. This 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.

Roger Jönsson of Faiveley Transport (4+5)

Håkan Fredriksson of SweMaint (5)

PROGRAMME AREAS CHARMEC STAGE 4

According to the Principal Agreement dated 19 June 2003, the Competence Centre CHARMEC should work within six overall programme areas during Stage 4, 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 the Stage 2 and 3 programme areas.

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 is in turn 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 of different types and conditions of trains, tracks and operations. Theoretical, 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. There should be the creation of a knowledge base 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. For both passenger and freight trains there seems to be considerable potential for improvement. 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 Stage 4, Chalmers University of Technology has been a partner, through CHARMEC, in several EU (European Union) projects in railway mechanics within the 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 financing of the EU projects. It should be noted that the legal entity signing the EU contracts on our part is Chalmers University of Technology.

Programme area 6
Parallel Special Projects
(Parallella SpecialProjekt, SP)

At their 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 research results.

SUMMARY OF CHARMEC STAGE 4

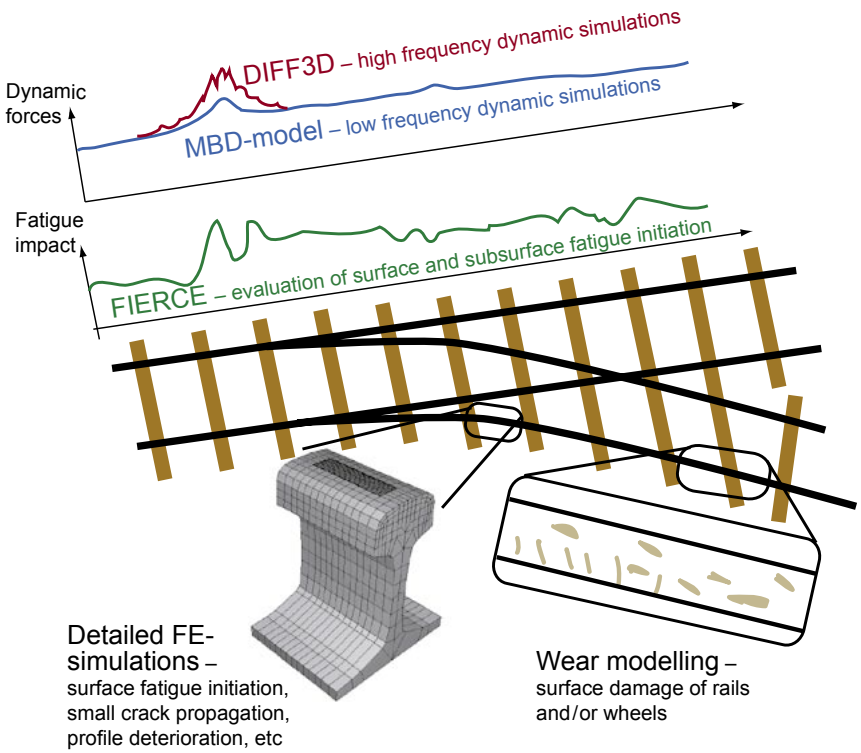
Research at the Centre during Stage 4 has been carried out as planned. New member voestalpine Bahnsysteme from Austria (representing both the rail manufacturer voestalpine Schienen and the switch manufacturer VAE) has joined the Industrial Interests Group. A new agreement was reached between Chalmers University of Technology and Banverket (the Swedish National Rail Administration) on Banverket's participation in the CHARMEC Competence Centre during Stage 4, in accordance with the Principal Agreement with VINNOVA. The Board of CHARMEC met as follows:

4	September	2003	9	March	2005
12	November	2003	1	June	2005
23	February	2004	6	October	2005
9	June	2004	1	February	2006
8	September	2004	17	May	2006
1	December	2004			

Detailed minutes were taken at all meetings. Early decisions were made on the content and funding of the projects carried over from Stage 3 and of new projects started during Stage 4. Since all CHARMEC parties are represented on the Board, the Board meetings have functioned as an efficient combination of working group and decision-making body. The two full-scale outdoor test-stands at Surahammar for braking experiments and noise measurements have been used. International evaluations of CHARMEC were performed in March 1997, March 2000 and March 2003, see CHARMEC's previous Biennial and Triennial Reports. No such evaluation took place during Stage 4.

The NUTEK/VINNOVA ten-year funding of CHARMEC, totalling KSEK 6000 per year, ended on 30 June 2005. Additional contributions from Banverket and Chalmers University of Technology replaced the VINNOVA funding during the last year (1 July 2005 – 30 June 2006) of CHARMEC's Stage 4. In addition, two separate applications from CHARMEC researchers to VINNOVA were approved and have resulted in three-year funding of the new three railway mechanics projects TS11, VB10 and MU18 as reported below. MU18 started in April 2006 and VB10 in May 2006 whereas TS11 will start later on. It should be noted that the CHARMEC Board had decided in spring 2003 to extend Stage 4 from VINNOVA's two years to three years and that the contracted funding from Banverket and the Industrial Interests Group was extended accordingly.

On the initiative of CHARMEC's Board, a round of interviews with Banverket and the individual members of the Industrial Interests Group took place in August 2004 and was summed up in a ten-page document. Research needs were identified, which later formed the basis for the Board's decisions regarding the start of new projects. A general conclusion was that all work within CHARMEC should continue to have a strong scientific foundation. A new round of interviews took place in April 2005, when the parties drew up a list of preferences among the proposed research projects. High priority was given to low noise emission, low maintenance costs and overall optimization, all with consideration given to future higher train speeds, increased axle loads and better wheel and rail materials. Greater involvement by senior researchers was suggested. Finally, a documented workshop "CHARMEC Road Map" was held at Chalmers in November 2005 with participants from the Board and from research groups at Chalmers. When selecting new projects to be run by CHARMEC, the Board paid attention to a proper balance between the following: fundamental research vs applied



Integration of research results from the CHARMEC projects. For DIFF3D and FIERCE, see projects TS4 and MU9 on pages 15 and 40

research, PhD students vs senior researchers, applicable for industry vs researchable for the University, and vehicle projects vs track projects.

The staff attached to the Centre, both at Chalmers (29 project leaders/principal advisers/senior researchers and 22 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. There have been frequent meetings between university researchers and those working in industry, and these meetings have resulted in both increased involvement in long-term industrial knowledge development and deeper insight into the working potential of the University. Mutual learning has taken place. For details of the concrete results achieved in the business activities of CHARMEC's industrial partners, see under the projects in the following.

Nine licentiate theses and six PhD dissertations in railway mechanics were presented by CHARMEC's researchers during Stage 4 up to June 2006, see page 76. In addition, 63 articles were published (or accepted for publication) in international scientific journals with a referee system, 43 papers were published in the proceedings of international conferences with a referee system, several EU reports were delivered, 36 research reports were edited in our own series of English-language research publications (without being internationally published) etc, nine 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 further information on these publications, see the lists under the projects described in the next section. One of our six new PhDs during Stage 4 is continuing his work at the University, two have been employed by a consultancy doing work in railway mechanics, and the remaining three now have employers that are not related to railways.

As was the case during Stages 1, 2 and 3, four seminars are usually held during the morning of the same day that the Board meets in the afternoon. All the CHARMEC Board members, project leaders, researchers and others (approximately 120 people) are invited to the seminars and to the lunch that follows. The seminars, at which all the project leaders/supervisors and PhD students present and discuss their projects, follow a rolling annual schedule. With effect from Stage 4, members of the CHARMEC Board and Industrial Interests Group are also scheduled as speakers during the morning seminars, where they present their organizations and their expectations regarding CHARMEC: Peter Pointner and Håkan Anderson (voestalpine Bahnsysteme) on 23 March 2004, Roger Jönsson (SAB WABCO Group) on 9 June 2004, Håkan Tirus (SL Infrateknik) on 8 September 2004, Björn Paulsson (Banverket and CHARMEC) on 9 March 2005, Rikard Bolmsvik (Abetong Teknik and heavy haul sleepers) on 1 June 2005, Henrik Tengstrand and Stefan Östlund (Bombardier Transportation, KTH Railway Group and Green Train Programme) on 1 February 2006, and Björn Paulsson (Banverket and EU project INNOTRACK) on 17 May 2006.

The continued participation by the CHARMEC researchers in EU projects (Fifth and Sixth Framework Programmes) has expanded our collaboration with companies, universities, institutes, public agencies and consultancies all over Europe. CHARMEC's network linked to the EU projects comprises some 100 organizations in 19 countries, see under projects EU6 to EU10 in the following. We also co-operate with railway bodies in Australia, Canada, Japan, South Africa and the USA.

A measure of the scientific standard achieved in the activities of the University and industry at Chalmers Railway Mechanics in the international arena is the high level of acceptance of articles for journals and contributions to conferences. In total, around 275 such articles and contributions have been published internationally so far. A total of 30 licentiate degrees and 23 PhD degrees in railway mechanics have been awarded to date (December 2006) at Chalmers, see again page 76.

CHARMEC runs no special courses, undergraduate or graduate, 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 the students. Several undergraduate students have been involved in project work and/or have written their MSc theses in railway mechanics.

For special events and achievements during Stage 4, see page 84. It is obvious, in retrospect, that without the framework and support established through the NUTEK/VINNOVA Competence Centre concept, the rather small university/industry collaboration in railway mechanics that already existed at Chalmers in 1994/95 could not have expanded, intramurally and extramurally, nationally and internationally, as it has done during the eleven years of CHARMEC's Stages 1, 2, 3 and 4.

PROJECTS AND RESULTS

The publications listed under the projects in the following are all those not previously registered in CHARMEC's Biennial and Triennial Reports 1 July 1995 – 30 June 2003 (Stages 1, 2 and 3), or which at that time were incomplete (not yet printed). Several minor reports have been omitted. Internal reports that later resulted in international publication 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 the partners in the EU1 – EU5 projects is given in the CHARMEC Biennial Report for Stage 1. The EU6, EU7 and EU8 projects (also now concluded) belonged to the Fifth Framework Programme. The scope of the EU1 – EU8 projects and a list of the partners in the EU6 – EU8 projects are given in the CHARMEC Triennial Report for Stage 3.

The EU9 and EU10 projects belong to the Sixth Framework Programme and are to be found under EU's Priority 6 – Sustainable Development, Global Change and Eco Systems. The total scope of these two projects and a list of the partners are given in the following. It should be noted that access for external parties to EU documents supplied by us and by others is often limited.

The departments where the 54 listed CHARMEC projects (TS1 – SP13) 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 16 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.

When a budget is given as a sum, e g "Stage 3: KSEK 500+750+500" in project TS7, this signifies that the CHARMEC Board has arrived at several successive budget decisions. As for the project budgets given for Stage 5, these only include the sums allocated by the Board up to December 2006.

The abbreviation *Lic Eng* stands for the intermediate academic degree *Licentiate of Engineering,* see page 76.

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 de constructions des 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 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 of 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 the CHARMEC Triennial Reports from Stages 2 and 3. The article below has been published since the latter report was edited.

Jens Nielsen and Johan Oscarsson: Simulation of dynamic train/track interaction with state-dependent track properties, *Journal of Sound and Vibration,* vol 275, nos 3-5, 2004, pp 515-532

PhD student Johan Oscarsson (doctorate earned in April 2001) of project TS1. Photo taken 2000 in the Chalmers Solid Mechanics laboratory. For photos of Thomas Abrahamsson and Jens Nielsen, see pages 15 and 24. For a new photo of Johan Oscarsson, see page 74

TS2. RAILHEAD CORRUGATION FORMATION

Räffelbildning på rälhuvud
Riffelbildung auf der Schienenoberfläche
Formation de l'usure ondulatoire sur les rails

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 employed as Associate Professor at Chalmers Solid Mechanics) was her supervisor. The faculty-appointed external examiner at the dissertation was Dr David J Thompson of 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 the CHARMEC Biennial and Triennial Reports from Stages 1 and 2.

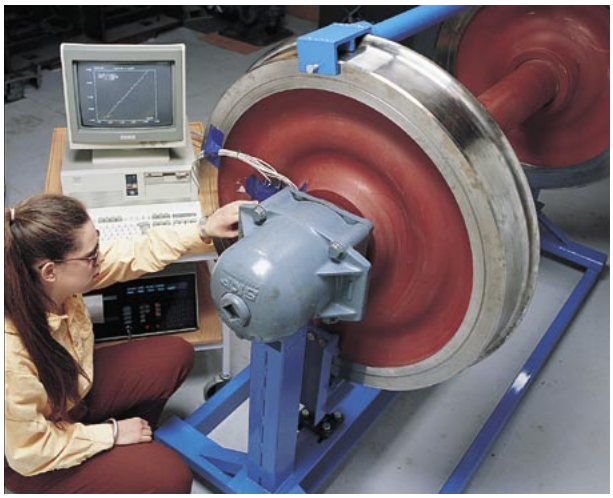
PhD student Annika Igeland of project TS2 and Dr David J Thompson of ISVR at the public defence of her doctoral dissertation (examination in public) in January 1997. For a photo of Tore Dahlberg, see page 63

TS3. SLEEPER AND RAILPAD DYNAMICS

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

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 to September the same year, when she left Chalmers. Tore Dahlberg (then employed as Associate Professor at Chalmers Solid Mechanics) was her supervisor. The faculty-appointed external examiner of the dissertation was Professor George A Lesieutre of 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 the Goose Hill measurements 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 the CHARMEC Biennial and Triennial Reports from 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 63

TS4. LATERAL TRACK DYNAMICS

Lateraldynamik och korrugering
Lateraldynamik der Gleiskonstruktionen
Dynamique latérale de voies ferrées

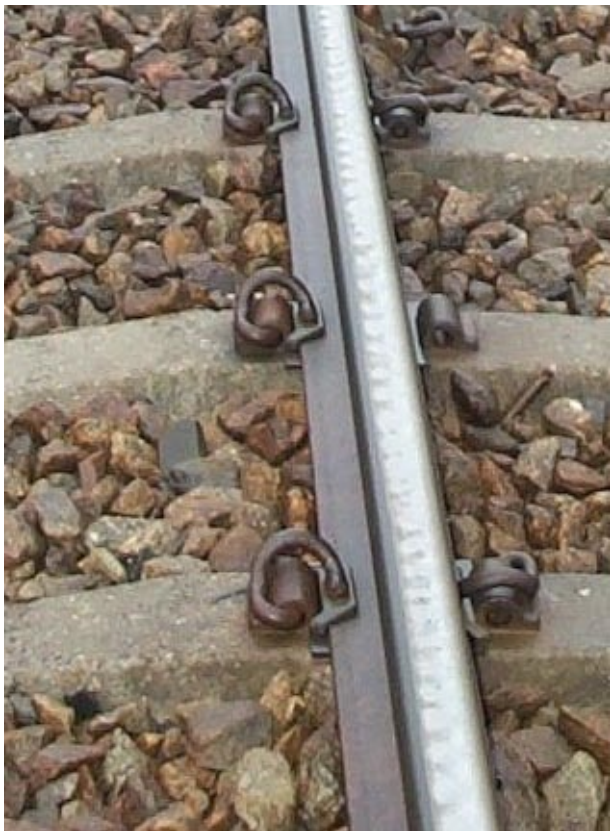
The TS4 project was completed with Clas Andersson's successful defence in public of his doctoral dissertation in June 2003. He continued his work at CHARMEC in the TS7 project up to December 2003, when he left Chalmers. Professor Thomas Abrahamsson and Docent Jens Nielsen supervised Clas Andersson's 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.

In the TS4 project, 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. FE models of a bogie wheelset and the rail are employed. Like the earlier version DIFF, the new DIFF3D works in the time domain.

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 the CHARMEC Triennial Reports from Stages 2 and 3. The article below has been published internationally since the latter report was edited.

Clas Andersson and Anders Johansson: Prediction of rail corrugation generated by three-dimensional wheel/rail interaction, *Wear,* vol 257, nos 3-4, 2004, pp 423-434

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



Short pitch corrugation at Kilsmo on the Western Main Line in Sweden

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

Orunda hjul – orsaker och konsekvenser
Unrunde Räder – Ursachen und Konsequenzen
Défauts de rondeur des roues – causes et consequences

Project leader and supervisor	Docent Jens Nielsen, Applied Mechanics
Assistant supervisor	Professor Roger Lundén, Applied Mechanics
Doctoral candidate	Anders Johansson (from 2000-08-01; Lic Eng September 2003; PhD September 2005)
Period	1998-05-01–2005-09-30
Chalmers budget (excluding basic university resources)	Stage 2: kSEK 1 300+150 Stage 3: kSEK 2 150+850+200+100 Stage 4: kSEK 1 300+600+300
Industrial interests in-kind budget	Stage 2: kSEK 300+200+100 *(Banverket+SJ+Duroc)* Stage 3: kSEK 300+100+50 *(Banverket+Duroc+TrainTech)* Stage 4: kSEK 100+100+50 *(Banverket+Duroc+TrainTech/ Interfleet Technology)*

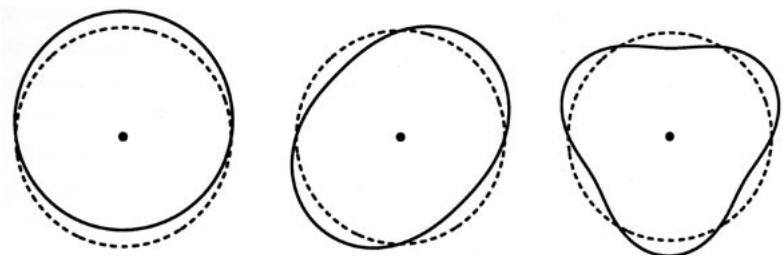
For a photo of Roger Lundén, see page 26.

From the left: PhD student Elias Kassa (licentiate taken in December 2004) of project TS7, PhD student Anders Johansson (doctorate earned in September 2005) of project TS5, and their supervisor Docent Jens Nielsen. Photo taken at the SweMaint maintenance workshop in Gothenburg in 2003

The TS5 project was completed with Anders Johansson's successful defence in public of his doctoral dissertation (see below) in September 2005. The faculty-appointed external examiner of the dissertation was Dr Simon Iwnicki, Principal Lecturer at the Department of Engineering and Technology at Manchester Metropolitan University, UK.

Railway traffic with out-of-round wheels leads to noise generation and also to high dynamic stresses in both track and vehicle with fatigue fracture as the most serious consequence. Through literature studies, full-scale field experiments, out-of-roundness measurements and numerical simulations, defects around the complete wheel circumference (e g, polygonal wheels) and local defects (e g, wheel flats) have been investigated. Wheel tread irregularities occurring in different types of train traffic in Sweden (high-speed, passenger, freight, commuter, subway) have been assessed. 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.

Measured responses were used to calibrate numerical models for simulation of train/track interaction in the time domain. The general three-dimensional train/track model used in the computer code DIFF3D, see project TS4, was further developed to include improved rolling contact mechanics and wear models. A powerful numerical tool for qualitative and quantitative prediction of wheel out-of-roundness and rail corrugation growth was subsequently obtained.



Examples of wheel out-of-roundness in project TS5: eccentricity, ovality and polygonalization

TS5. (cont'd)

Certain wavelength-fixing mechanisms due to the track properties have been discovered. The influence of a corrugated wheel tread on the growth of the corrugation on the railhead was found to be negligible. See also the CHARMEC Triennial Reports from Stages 2 and 3. The reference group of project TS5 included members from Banverket, Bombardier Transportation and Interfleet Technology and held meetings in Gothenburg, Stockholm and Siegen (Germany).

Anders Johansson: Out-of-round railway wheels – literature survey of wheel removal criteria and damage to track from impact loads, Research Report 2003:7, *Chalmers Applied Mechanics,* Gothenburg 2003, 28 pp

Anders Johansson: Out-of-round railway wheels – measurements of out-of-roundness, transverse profile and surface hardness, Research Report 2004:1, *Chalmers Applied Mechanics,* Gothenburg 2004, 40 pp

Anders Johansson: Integrerade beräkningsmodeller för användning inom Banverksprojektet "Hjulskador" (Integrated numerical models for use within the Banverket project "Wheel Damage"; in Swedish), Research Report 2004:11, *Chalmers Applied Mechanics,* Gothenburg 2004, 19 pp

Anders Johansson and Clas Andersson: Out-of-round railway wheels – a study of wheel polygonalization through simulation of three-dimensional wheel/rail interaction and wear, *Vehicle System Dynamics,* vol 43, no 8, 2005, pp 539 - 559

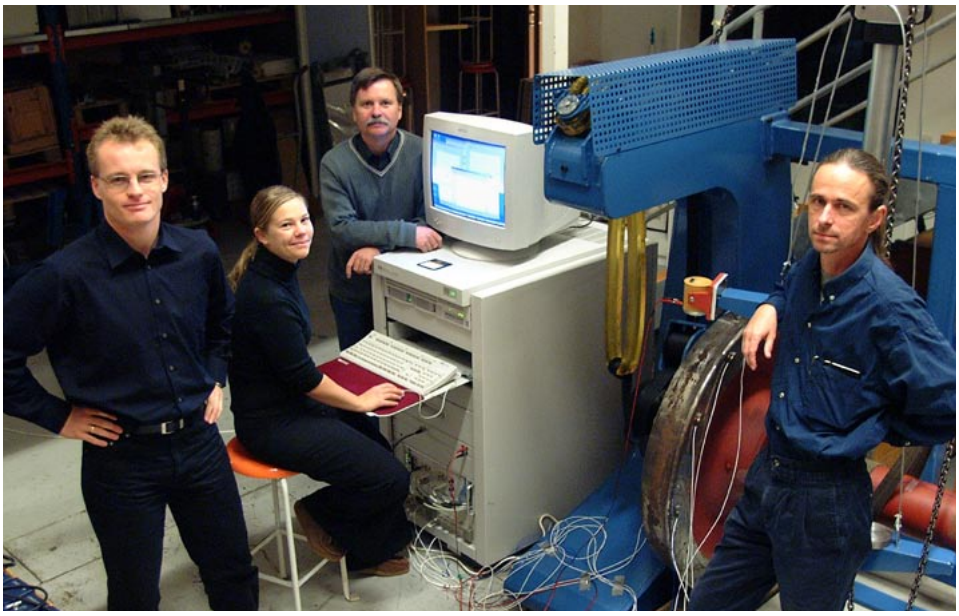
Anders Johansson and Jens Nielsen: Out-of-round railway wheels – influence of powered wheelsets with tread braking on rail corrugation growth, *19th IAVSD Symposium, Dynamics of Vehicles on Roads and Tracks, Poster Papers,* Milan (Italy) August – September 2005, 2 pp (available on CD)

Anders Johansson and Jens Nielsen: Rail corrugation growth – influence of powered wheelsets with wheel tread irregularities, *Wear* (accepted for publication)

Anders Johansson: Out-of-round railway wheels – a survey of models for simulation of wheel/rail contact and wear, condensed and revised version of Research Report 2003:3, *Chalmers Applied Mechanics,* Gothenburg 2005, 34 pp

Anders Johansson: Out-of-round railway wheels – causes and consequences: an investigation including field tests, out-of-roundness measurements and numerical simulations, Doctoral Dissertation, *Chalmers Applied Mechanics,* Gothenburg September 2005, 191 pp (introduction, summary and six appended papers)

Anders Johansson: Out-of-round railway wheels – assessment of wheel tread irregularities in train traffic, *Journal of Sound and Vibration,* vol 293, nos 3-5, 2006, pp 795-806 (also presented at *8th International Workshop on Railway Noise (IWRN8)* in Buxton/Derbyshire (UK) in September 2004)



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 at the wheelset test rig in the Chalmers Applied Mechanics laboratory in 2003

TS6. IDENTIFICATION OF DYNAMIC FORCES IN TRAINS

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

Project leader and supervisor	Professor Thomas Abrahamsson, Applied Mechanics
Assistant supervisor	Dr Peter Möller, Senior Lecturer, Applied Mechanics
Doctoral candidate	Mr Lars Nordström (from 2000-09-01; Lic Eng January 2003; PhD November 2005)
Period	2000-07-01–2005-11-30
Chalmers budget (excluding university basic resources)	Stage 3: KSEK 2 150 Stage 4: KSEK 1 300
Industrial interests in-kind budget (Bombardier Transportation)	Stage 3: KSEK 400 Stage 4: KSEK 300

For a photo of Thomas Abrahamsson, Peter Möller and Lars Nordström, see previous page.

The TS6 project was completed with Lars Nordström's successful defence in public of his doctoral dissertation (see below) in November 2005, when he also left Chalmers. The faculty-appointed external examiner of the dissertation was Professor Anders Klarbring of the Department of Mechanical Engineering at Linköping Institute of Technology in Sweden.

Knowledge of the time-variant contact forces between railway wheels and rails is important since these forces govern the design of wheels, bogies, car bodies and tracks. They cause wear and fatigue, impair coach comfort and lead to ground vibrations. Today no methods are available for direct measurement in the contact patch of the forces acting on a rolling wheel. Special measuring wheels with strain gauges are being used to register indirectly the variation in magnitude of the contact forces within a limited frequency range.

The general aim of project TS6 has been to study, on a broad scale, possible methods for the calculation of forces acting at locations inaccessible for direct measurements. A solution to a so-called inverse problem is sought. Starting from a basis of measured accelerations and other responses in appropriate positions and directions on board 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 nonlinear systems being either time-invariant or time-variant. The investigated time-domain methods are Dynamic Programming (DP), Sum of Weighted Accelerations Technique (SWAT), Inverse Structural Filtering (ISF), Partial Modal Matrix Technique (PMMT) and Wavelet Parameterization Method (WPM). For linear time-variant systems, DP was preferred and has been further developed. The sensitivity of the solution 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 have been 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 Applied Mechanics at Chalmers were also used. Sensor positions and favourable time delays of sensor signals were investigated.

In principle, the stated inverse problem in its general form is unsolvable unless some a priori assumptions about load positions etc are made. The mathematical ill-posedness complicates the handling of the unavoidable noise in measurement data. More work in the area of load identification is required. See also the CHARMEC Triennial Reports from Stages 2 and 3.

Lars Nordström and Patrik Nordberg: A time delay method to solve non-collocated input estimation problems, *Mechanical Systems and Signal Processing,* vol 18, no 6, 2004, pp 1469 1483

Lars Nordström: Input estimation in structural dynamics, Doctoral Dissertation, *Chalmers Applied Mechanics,* Gothenburg November 2005, 141 pp (introduction, summary and five appended papers)

Lars Nordström: A dynamic programming algorithm for input estimation on linear time-variant systems, *Computer Methods in Applied Mechanics and Engineering,* vol 195, nos 44-47, 2006, pp 6407-6427

Lars Nordström, Håkan Johansson and Fredrik Larsson: A strategy for input estimation with sensitivity analysis, *International Journal for Numerical Methods in Engineering,* vol 69, no 11, 2007, pp 2219-2246 (also presented at *8th US National Congress on Computational Mechanics (USNCCM8)* in Austin TX (USA) in July 2005)

Lars Nordström: Comments on 'A dynamic programming algorithm for input estimation on linear time-variant systems' (submitted to *Computer Methods in Applied Mechanics and Engineering*)

TS7. DYNAMICS OF TRACK SWITCHES

Spårväxlars dynamik
Dynamik von Eisenbahnweichen
Dynamique des aiguilles de voies ferrées

Project leader and supervisor	Professor Jens Nielsen, Applied Mechanics
Assistant supervisor	Professor Tore Dahlberg, Linköping Institute of Technology
Doctoral candidate	Mr Elias Kassa, (from 2002-04-01; Lic Eng December 2004)
Period	2002-04-01–2006-06-30 (–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 2 050+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 100+50+100 *(Banverket+SL Technology +voestalpine Bahnsysteme)*

For photos of Jens Nielsen and Tore Dahlberg, see pages 24 and 63

The aim of the TS7 project is to obtain a basic understanding of how railway switches (turnouts) should be developed in order to achieve lower maintenance costs, fewer traffic disruptions and longer inspection intervals. The effects of geometrical design, manufacturing tolerances and operational wear on the performance are being investigated in simulations which are calibrated and validated using in-field measurements. Usage of the terms switch, turnout and points varies, see sketch.

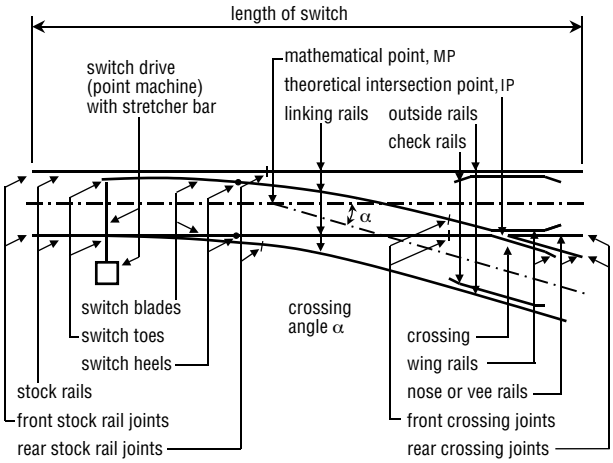
Dynamic train/track interaction is more complex in railway turnouts than on ordinary tangent or curved tracks. Multiple contacts between wheel and rail are common and severe impact loads with a broad frequency content are induced. The absence of transition curves at the entry and exit of the turnout, and the cant deficiency, lead to large wheel/rail contact forces and passenger discomfort when the train is switching into the turnout track.

Two alternative multibody 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 is derived using the commercial

PhD student Elias Kassa (licentiate gained in December 2004) in project TS7. Photo taken in 2006

MBS software GENSYS. The second model is based on an in-house multibody dynamics formulation that may account for the structural flexibility of both train and track components (including finite element models and co-ordinate reduction methods). The variation in rail profile is accounted for. Contact between the back of the wheel flange and the check rail (guard rail), when the wheelset is steered through the crossing, is considered. Good agreement between the results from the two models has been observed. The finite element model of the turnout is now being integrated into the in-house software DIFF3D, see project TS4.

From a parameter study, it has been found that the normal contact force increases with train speed and axle load. Highly worn wheel profiles may result in high contact forces. A combination of high axle load and low train speed results in an increased wear index. A stochastic



Sketch of a right-hand railway turnout with terminology for "switch and crossing work" according to the draft European standard prEN 13232-1 of October 2002. 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"

TS7. (cont'd)

analysis technique has been adopted to incorporate the uncertainty of the wheel profile as measured in project TS5. There has been close co-operation with the CHARMEC partner VAE in Austria, see under voestalpine Bahnsysteme on page 89. Field tests have been performed in collaboration with Banverket in May 2006 at Härad (close to Strängnäs) on Svealandsbanan in Sweden. Wheel/rail contact forces for various train speeds and routes through a turnout UIC60-760-1:15 were measured. Dr Clas Andersson of project TS4 assisted in project TS7 from March to December 2003.

Elias Kassa visited VAE in Zeltweg and the University of Leoben (Austria) on 25-28 May 2005. The joint reference group for projects TS7 and MU14 has members from Abetong Teknik, Banverket, Luleå University of Technology, Storstockholms Lokaltrafik (SL), VAE and voestalpine Schienen. Elias Kassa took his licentiate in December 2004 with Dr Johan Oscarsson of Interfleet Technology introducing the discussion at the final seminar. It is planned that Elias Kassa will take his PhD in autumn 2007. See also the CHARMEC Triennial Report from Stage 3.

Elias Kassa: Simulation of dynamic interaction between train and turnout, Licentiate Thesis, *Chalmers Applied Mechanics,* Gothenburg December 2004, 56 pp

Elias Kassa, Clas Andersson and Jens Nielsen: Simulation of dynamic interaction between train and railway turnout, *Vehicle System Dynamics,* vol 44, no 3, 2006, pp 247-258

Elias Kassa and Göran Johansson: Simulation of train–turnout interaction and plastic deformation of rail profiles, *Vehicle System Dynamics* (in press. Also presented at *19th IAVSD Symposium* in Milan (Italy) in August – September 2005)

Martina Wiest, Elias Kassa, Werner Daves, Jens Nielsen and Heinz Ossberger: Assessment of methods for calculating contact pressure in wheel/rail/switch contact, *Proceedings 7th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2006),* Brisbane (Australia) September 2006, vol 2, pp 501-508

TS8. INTEGRATED TRACK DYNAMICS

Integrerad spårdynamik
Integrierte Gleisdynamik
Dynamique intégrée de la voie

Project leader	Professor Jens Nielsen, Applied Mechanics
Doctoral candidate	None (only senior researcher in this project)
Period	2003-10-01–2006-06-30 (– 2009-06-30)
Chalmers budget (excluding university basic resources)	Stage 4: kSEK 1 500+700+350 Stage 5: kSEK 1 000
Industrial interests in-kind budget	Stage 4: kSEK 400 *(Banverket)* Stage 5: kSEK 200+50 *(Banverket+Abetong Teknik)*

For a photo of Jens Nielsen, see page 24

In this work, available software from relevant CHARMEC projects for analysis of dynamic train/track interaction, of wear and rolling contact fatigue of wheel and rail, and of ground vibrations and railway noise, are being extended and integrated. Calculated high-frequency wheel/rail contact forces are being validated against forces measured by Interfleet Technology during the field tests in October 2002 with an X2 passenger train on rough (corrugated) rails, see project SP3. The application of CHARMEC's computer programs DIFF and DIFF3D is being broadened better to handle frequencies below 50 Hz. The overall aim of the project is to develop a user-friendly computer tool for the rational design of the whole track and its individual components.

The CHARMEC software DIFF has participated in a worldwide benchmark test of models for railway track dynamic behaviour organized by Rail CRC at Queensland University of Technology in Brisbane, Australia. DIFF performed well, among software from Canada, China, Germany, UK and USA, with consistent results on wheel/rail contact forces, rail seat loads, and rail and sleeper bending moments. Simulations of wheel flat impacts have shown that there is a remarkable decrease in resistance against fatigue crack growth of a rail suffering from repeated impact loads. Thermal stresses due to seasonal variations have a significant additional effect on the fatigue life of the rail.

An insulated rail joint (see project SP8) has been found to alter the dynamic characteristics of the track. This

TS8. (cont'd)

effect, with its introduced local surface irregularity (dipped joint) on the rail, causes high wheel/rail contact load magnitudes. Stress concentrations and pertinent plastic deformations also occur at an insulated joint. The dynamic excitation caused by the rail joint will lead to increased rolling contact fatigue impact even at some distance from the joint.

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. The numerical time-domain model in DIFF has been integrated with the analytical frequency-domain model in project VB8. With the integrated code, a better coupling (via the ground) between adjacent sleepers is obtained, which is important when a bogie with its two wheelsets runs on the track. Docent Jonas Ringsberg (see project MU6) has taken part in the work on wheel flat impact on crack propagation in rails.

Jens Nielsen, Anders Ekberg, Elena Kabo and Roger Lundén: Integrated analysis of dynamic train/track interaction and rolling contact fatigue, *Proceedings 14th International Wheelset Congress,* Orlando Florida (USA) October 2004, 15 pp (available on CD. Also listed under project MU9)

Jens Nielsen, Jonas Ringsberg and Luis Baeza: Influence of railway wheel flat impact on crack growth in rails, *Proceedings 8th International Heavy Haul Conference,* Rio de Janeiro (Brazil) June 2005, pp 789-797

Jens Nielsen: Utvärdering av hjulskadedetektorer (Assessment of wheel impact load detectors; in Swedish), *Chalmers Applied Mechanics,* Gothenburg February 2005, 11 pp

Jens Nielsen, Anders Ekberg and Roger Lundén: Influence of short-pitch wheel/rail corrugation on rolling contact fatigue of railway wheels, *IMechE Journal of Rail and Rapid Transit,* vol 219, no F3, 2005, pp 177-187 (also listed under projects MU9 and SP11). In July 2006, this paper received the *IMechE Railway Division W A Agnew / C N Goodall Award 2005*

Elena Kabo, Jens Nielsen and Anders Ekberg: Prediction of dynamic train/track interaction and subsequent material deterioration, *Proceedings 19th IAVSD Symposium,* Milan (Italy) August– September 2005, 3 pp (available on CD. Also listed under project MU9)

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* (in press. Also listed under projects MU9 and SP8)

Anders Karlström, Jens Nielsen and Anders Boström: Train/track-soil numerical-analytical interaction model in the time domain, Research Report 2006:8, *Chalmers Applied Mechanics,* Gothenburg 2006, 22 pp (also listed under project VB8)

Anders Ekberg, Elena Kabo, Jens Nielsen and Roger Lundén: Subsurface initiated rolling contact fatigue of railway wheels as generated by rail corrugation, *Chalmers Applied Mechanics,* Gothenburg 2006 (submitted for international publication. Also listed under project MU10)

Jens Nielsen: High-frequency vertical wheel/rail contact forces – validation of a prediction model by field testing, *Proceedings 7th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2006),* Brisbane (Australia) September 2006, pp 41-48 (also listed under project SP11)

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

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
Doctoral candidate	Ms Johanna Lilja, (from 2004-02-09; Lic Eng November 2006)
Period	2004-01-01–2006-06-30 (–2009-06-30)
Chalmers budget (excluding university basic resources)	Stage 4: kSEK 1 825+200 Stage 5: kSEK 1 925+230
Industrial interests in-kind budget	Stage 4: kSEK 300 *(Abetong Teknik)* Stage 5: kSEK 400 *(Abetong Teknik)*

For photos of Johanna Lilja, Thomas Abrahamsson and Jens Nielsen, see pages 21 and 24

Project TS9 focuses on the design loads for a sleeper installed in a track carrying different types of traffic. Results from earlier CHARMEC projects are being exploited and new in-field measurements performed. 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. A stochastic approach to the modelling of subgrade, ballast and traffic is being used and a probabilistic design method for sleepers is being developed, setting out from test data. Optimization will be carried out using the in-house program DIFF, which will be further developed to handle stochastic variations.

A finite element (FE) model of a sleeper has been established, employing the superelement technique. The model has been used in the development of a method to estimate the required number of sensors and their location under the sleeper in the planned in-field tests to find the pressure distribution imposed by the ballast. The importance of the ballast conditions when studying the dynamic behaviour of a sleeper under loading has been clarified. The sensors must be located very close to one another if experimental data are to be of value in a subsequent stress analysis. The required sensor closeness is in the order of a few centimetres.

A so-called sleeper performance function (probability of cracking because of too high bending moments in the rail seat and centre cross-sections) has been established and the feasibility of a number of probabilistic methods for sleeper design has been studied. To estimate the importance of the variation in the selected stochastic parameters (train speed, axle load, sleeper spacing, railpad stiffness, total ballast stiffness, non-uniformity of ballast stiffness), a fractional factorial design method has been applied.

An instrumented sleeper with load cells over its bottom surface has been designed and manufactured. The first in-field measurements took place on 14 September 2006 at Harrträsk (close to Gällivare) on the Iron Ore Line in Northern Sweden. The reference group of project TS9 includes members from Abetong Teknik, Banverket and Växjö University.

Johanna Lilja gave the final seminar for her licentiate thesis (see below) on 23 November 2006 with Björn Sjödin, Lic Eng, of Siemens Industrial Turbomachinery in Finspång (Sweden) introducing the discussion.

Jonas Zachrisson: Reliability optimization with application to sleeper design, MSc Thesis 2004:6, *Chalmers Applied Mechanics,* Gothenburg December 2004, 41 pp. This work was awarded Swedtrain's (Swedish Association of Railway Industries) Prize for 2005 for Best Master's Thesis in Railway Technology

Johanna Lilja, Thomas Abrahamsson and Jens Nielsen: Experimental investigation of stochastic boundary conditions – planning a railway sleeper test, *Proceedings 24th International Modal Analysis Conference (IMAC XXIV),* St Louis MO (USA) January-February 2006, 7 pp (available on CD)

Benoît Duveiller: Statistical evaluation of structural dynamics problems with application to sleeper design, MSc Thesis 2006:47, *Chalmers Applied Mechanics,* Gothenburg June 2006, 79 pp

Johanna Lilja: Preliminaries for probabilistic railway sleeper design, Licentiate Thesis, *Chalmers Applied Mechanics,* Gothenburg November 2006, 70 pp (summary and two appended papers)

Under sleeper pads (courtesy Getzner Werkstoffe GmbH)

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 Teknik, and Professor Jens Nielsen, Applied Mechanics
Co-worker	Dr Bo Andreasson and Dr Johan Jonsson, WSP Consulting, and Dr Anders Johansson, Applied Mechanics/ Epsilon HighTech
Doctoral candidate	None (only senior researchers in this project)
Period	2005-06-01–2006-06-30 (– 2007-12-31)
Chalmers budget (excluding university basic resources)	Stage 4: kSEK 300+100 kSEK 150+150 *(Getzner Werkstoffe/ Christian Berner+SBB)*
Industrial interests in-kind budget	Stage 4: kSEK 100+ 300 *(Banverket+Abetong Teknik)* Stage 5: kSEK 150+150 *(Abetong Teknik+Banverket)*

For photos of Rikard Bolmsvik, Jens Nielsen and Anders Johansson, see pages 16, 24 and 75

Under Sleeper Pads (USP) are installed primarily in an effort to reduce structure-borne vibrations and ballast damage, and to allow for a prospective reduced depth of the ballast layer. The objective of project TS10 is to increase the understanding of the influence of USP on the dynamic response of the assembled track structure and its individual components. Results from field tests, with and without USP installed, will be used to validate a numerical model. In a literature survey (see below) it was concluded that the present understanding of the functioning of USP is rather limited. The long-term effects of introducing USP will not be covered within the present project.

The project was prepared and planned at two meetings held at Chalmers on 21 March 2005 and at Abetong Teknik in Växjö on 12 May 2005. Meetings with SBB (Schweizerische BundesBahnen) were held at Chalmers on 14 June 2005 and at SBB in Bern (Switzerland) on 29 September 2005. Meetings after the start of project TS10 were held in Växjö on 21 October 2005, at Chalmers on 12 December 2005 and in Linköping on 25 April 2006. Bo Andreasson of WSP Consulting was invited to present his work for Banverket, leading to the use of USP on a stretch of track on the Swedish West Coast Line at Furet close to Halmstad. Agreements on financial contributions from SBB and Getzner Werkstoffe GmbH (through their Swedish agency Christian Berner AB) have been made. Jens Nielsen visited the pad producer Getzner Werkstoffe in Bludenz/Bürs (Austria) on 27-28 September 2005 to run an introductory course on the theory and use of CHARMEC's computer program DIFF. A visit to the Getzner laboratory that is being used for measurement of dynamic stiffness and damping of USP was also made.

Project plans dated 12 May 2005 and 12 May 2006 have been agreed upon. The co-ordinator Rikard Bolmsvik is also the Banverket representative in the UIC working group on USP. The track model in DIFF has been extended with viscoelastic models of railpads and USP, which improves the possibility to model the frequency-dependent properties of the resilient layers. A parametric study of the influence of USP on the dynamic performance of the track has been made by Anders Johansson using the programs DIFF and GroundVib (from VB8). Linköping University (Tore Dahlberg and co-workers) investigated the possibility of selecting USP stiffnesses so that the wheel/rail contact force variations are minimized.

Before the installation of USP at Furet on 18 November 2005, several measurements of track properties were performed. Track stiffnesses were measured using Banverket's Rolling Stiffness Measurement Vehicle (RSMV), track receptances were measured using impact excitation, and accelerations and strains of rails and sleepers were measured for several train passages (passenger coaches and freight wagons). The measurements will later be repeated to assess the influence of the installed USP. A measurement campaign on an SBB test track is being planned.

Project TS10 has a reference group that includes representatives from Banverket, Christian Berner AB, Getzner Werkstoffe GmbH and SBB Infrastruktur.

Rikard Bolmsvik: Influence of USP on the track response – a literature survey, *Abetong Teknik AB,* Växjö (Sweden) 2005, 15 pp

Anders Johansson: Under Sleeper Pads – influence on dynamic train/track interaction, Research Report 2006:02, *Chalmers Applied Mechanics,* Gothenburg 2006, 35 pp

Anders Johansson, Jens Nielsen, Rikard Bolmsvik, Anders Karlström and Roger Lundén: Under Sleeper Pads – influence on dynamic train/track interaction, *Proceedings 7th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2006),* Brisbane (Australia) September 2006, pp 583-592 (also listed under project VB8)

Andreas Lundqvist, Rikard Larsson and Tore Dahlberg: Influence of railway track stiffness variations on wheel/rail contact force, *Proceedings Workshop Track for High-Speed Railways,* Faculty of Engineering of the University of Porto (Portugal) October 2006, pp 67-78

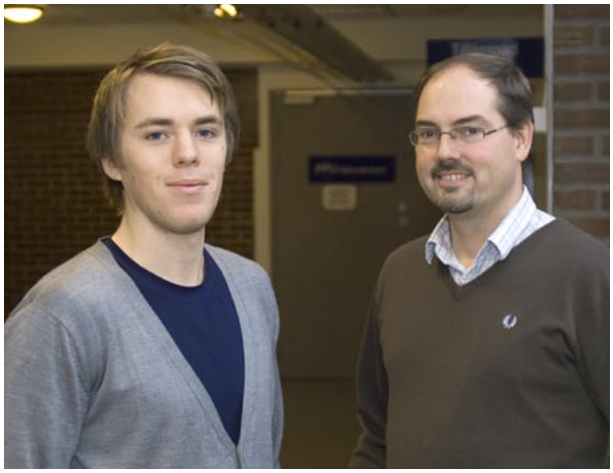
TS11. RAIL CORRUGATION GROWTH ON CURVES

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

Project leaders and supervisors	Professor Jens Nielsen, Applied Mechanics, and Dr Anders Frid, Bombardier Transportation Sweden
Doctoral candidate	Mr Peter Torstensson, MSc (from 2007-02-26)
Period	2005-06-01–2006-06-30 (–2012-02-29)
Chalmers budget (excluding university basic resources)	Stage 4: kSEK 125 Stage 5: kSEK 2050
Industrial interests in-kind budget	Stage 4: – Stage 5: kSEK 200+50+200 *(Banverket+SL Technology +voestalpine Bahnsysteme)*

For a photo of Anders Frid, see page 22 in the CHARMEC Triennial Report from Stage 2

The in-house simulation program DIFF3D, see project TS4, will be employed to further develop a model of the dynamic interaction between train and track on curves. The model should allow for detailed studies of the influence of the level of traction as well as wheel/rail friction, rail



PhD student Peter Torstensson (left) and his supervisor Professor Jens Nielsen in project TS11

cant, curve radius and non-symmetric rail profiles. The dynamic properties of both bogie and track will be considered. The distribution of stick and slip over the contact patch between wheel and rail will be calculated and used in a wear model for prediction of corrugation growth. A foundation will thus be laid for the prediction of rolling noise emission from a train negotiating a curve.

Projects TS11 and VB10 will be co-ordinated. These new projects are being financed partly by the Swedish research agency VINNOVA (through CHARMEC's budget).

VB1. STRUCTURAL VIBRATIONS FROM RAILWAY TRAFFIC

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

For a photo of Johan Jonsson, see page 27

Project VB1 was completed with Johan Jonsson's successful defence in public of his doctoral dissertation in June 2000. Professors Sven Ohlsson and Thomas Abrahamsson supervised the research. The faculty-appointed external examiner of the dissertation was Dr Christian Madshus of 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. See also the CHARMEC Biennial and Triennial Reports from Stages 1 and 2.

VB2. NOISE FROM TREAD BRAKED RAILWAY VEHICLES

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

Project leader and supervisor	Professor Roger Lundén, Applied Mechanics
Assistant supervisor	Dr Peter Möller, Senior Lecturer, Applied Mechanics
PhD students	Tore Vernersson (March 1994 to December 1997; Lic Eng September 1997; PhD June 2006 in Project SD4)
	Martin Petersson (from January 1998; Lic Eng October 1999)

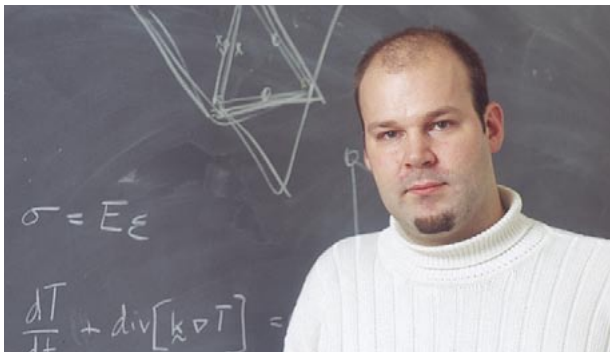
Note: VB2 has been part of a larger project with parallel funding directly from Adtranz Wheelset (now Lucchini Sweden), see SP1 on page 68

For photos of Roger Lundén, Peter Möller and Tore Vernersson, see pages 17 and 26

Freight trains run to a large extent at night, and have also proved noisier than passenger trains. The reason for the latter is that freight trains are nearly always tread-braked while passenger trains are disc-braked. Thermal interaction between the wheel and the brake blocks causes a corrugated tread on the wheel. For the running train this results in oscillating contact forces that excite vibrations in the wheel and rail, with noise radiation as a consequence. The aim of project VB2 was to understand the mechanisms behind the growth of tread corrugation and to try to reduce this.

Extensive braking experiments were performed in the test rig (inertia dynamometer) at Surahammar, see page 59, and mathematical modelling and numerical simulations were carried out. Brake blocks of cast iron, sintered material and composite material have been investigated. See further the CHARMEC Biennial and Triennial Reports from Stages 1, 2 and 3, and also project SD4 below.

The completion of project VB2 has been delayed. Tore Vernersson gained his licentiate in project VB2 and then transferred his work to projects VB3, VB4, EU1, EU8 and SD4. Martin Petersson has left Chalmers for employment elsewhere. CHARMEC's financial contribution to the project ended on 30 June 2001.



PhD student Martin Petersson (licentiate gained in October 1999) of project VB2. Photo taken in 2000

VB3. TEST RIG FOR RAILWAY NOISE

Provrigg för järnvägsbuller
Prüfstand für Schallfelder von Eisenbahnen
Banc de mesure pour bruits ferroviaires

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 is outdoors at the Adtranz Wheelset (now Lucchini Sweden) factory site in Surahammar. A special feature of RNTR is that wheelsets 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 wheelsets (or bogies) and 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 the CHARMEC Biennial and Triennial Reports from 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 bruits émis par le train et la voie

Project leader and supervisor	Professor Roger Lundén, Applied Mechanics
Assistant supervisors	Dr Anders Frid, Adtranz Sweden (now Bombardier Transportation Sweden)
	Docent Jens Nielsen, Applied Mechanics
Doctoral candidate	Mr Carl Fredrik Hartung (from 1999-04-01; Lic Eng November 2002)
Period	1998-07-01 – 2007-12-31
Chalmers budget (excluding university basic resources)	Stage 2: kSEK 1 200 Stage 3: kSEK 1 950 Stage 4: kSEK 500 Stage 5: –
Industrial interests in-kind budget	Stage 2: kSEK 200+200+200 *(Abetong Teknik+Adtranz Wheelset+SJ)* Stage 3: kSEK 300+600 *(Bombardier Transportation +Lucchini Sweden)* Stage 4: kSEK 100+100 *(Bombardier Transportation +Lucchini Sweden)* Stage 5: –

With higher speeds and axle loads, railway traffic is becoming 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 should demonstrate how the vibration and noise properties of various track and on-board components can be predicted for the running train.

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 whereas blue indicates a low level. A reflecting ground surface is used in this experiment. Photo taken in 2002

Carl Fredrik Hartung left Chalmers after taking his licentiate in November 2002. Since then the VB4 project has been partially discontinued. Tore Vernersson contributed early on in the project, and during Stage 5 he will resume the work with the RNTR using funds remaining from Stage 4. See further the CHARMEC Triennial Reports from 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

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 up to 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 of 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).

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

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 shear wave speed in 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 shown that the speed of the train and the properties of the clay play a major role. 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 the CHARMEC Triennial Reports from Stages 2 and 3. The following articles have been published since the latter of the two reports was edited.

Per Kettil, Torbjörn Ekevid and Nils-Erik Wiberg: Adaptive multigrid for finite element computations in plasticity, *Computers & Structures,* vol 82, no 28, 2004, pp 2413-2424

Torbjörn Ekevid, Håkan Lane and Nils-Erik Wiberg: Adaptive solid wave propagation – influences of boundary conditions in high-speed train applications, *Computer Methods in Applied Mechanics and Engineering,* vol 195, nos 4-6, 2006, pp 236-250

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 replaces, at least partially, 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
Übertragung von Vibrationen in Eisenbahnfahrzeugen
Transmission de vibrations dans les véhicules ferroviaires

Project leaders and supervisors	Professor Thomas Abrahamsson, Applied Mechanics Docent Tomas McKelvey, Signals and Systems
Doctoral candidate	Mr Per Sjövall (formerly Per Kalling) (from 2003-03-01; Lic Eng October 2004)
Period	2001-07-01 – 2006-06-30 (– 2008-02-29)
Chalmers budget (excluding university basic resources)	Stage 3: KSEK 1 250 Stage 4: KSEK 2 050 Stage 5: KSEK 1 250
Industrial interests in-kind budget (Bombardier Transportation)	Stage 3: KSEK 300 Stage 4: KSEK 200 Stage 5: KSEK 100

PhD student Per Sjövall (centre; licentiate gained in October 2004) and his supervisors Professor Thomas Abrahamsson (left) and Docent Tomas McKelvey in the VB7 project inspecting a bogie at Gothenburg railway station

Structure-borne vibrations and sound (SBV&S) are generated at contact between wheel and rail and are transmitted via the bogie structure into the car body. Sources of excitation are the periodic sleeper passages and the irregularities on the running surfaces of wheel and rail. The vibrations from sleeper passages are narrow-band and speed-dependent whereas the irregularities on wheels and rails most often generate broad-band vibrations.

The aim of the VB7 project is 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). Parameters should be identified from experimental results. To validate a devised subsystem identification procedure, a small-scale physical experiment has been designed. The laboratory test structure is composed of two substructures that are coupled through compliant spring elements.

It has been found that a model obtained from generic (black-box) system identification can be improved if a priori knowledge about the tested structure can be taken into account. Examples of such knowledge 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 a subsystem model.

Although subsystem identification can successfully be applied to synthetic models and data, it has been found that subsystem identification based on experimental data is significantly harder. So far, experimental data have been gathered from the simple laboratory set-up.

Per Sjövall gave his licentiate seminar on 1 October 2004 with Anders Daneryd, Lic Eng, of ABB Corporate Research in Västerås introducing the discussion. Per Sjövall was on parental leave during the autumn term 2005. The reference group of project VB7 includes people from Banverket, Bombardier Transportation, Interfleet Technology and KTH Railway Group.

Per Kalling, Thomas Abrahamsson and Tomas McKelvey: Synthesis of subsystem state-space models, Research Report 2004:4, *Chalmers Applied Mechanics,* Gothenburg 2004, 24 pp

Per Kalling, Thomas Abrahamsson and Tomas McKelvey: Subsystem state-space model identification and its sensitivity to test variability, *Proceedings ISMA (International Software Measurement & Analysis) 2004 Conference on Noise & Vibration Engineering,* Leuven (Belgium) September 2004, 15 pp (available on CD)

Per Sjövall: Component synthesis and identification in structural dynamics, Licentiate Thesis, *Chalmers Applied Mechanics,* Gothenburg September 2004, 52 pp (summary and two appended papers)

Per Sjövall, Tomas McKelvey and Thomas Abrahamsson: Constrained state-space system identification with application to structural dynamics, *Automatica,* vol 42, no 9, 2006, pp 1539-1546. Also presented at *14th IFAC (International Federation of Automatic Control) Symposium on System Identification (SYSID2006)* in Newcastle (Australia) March 2006, see Preprints pp 1294-1299

VB8. GROUND VIBRATIONS FROM RAILWAYS

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

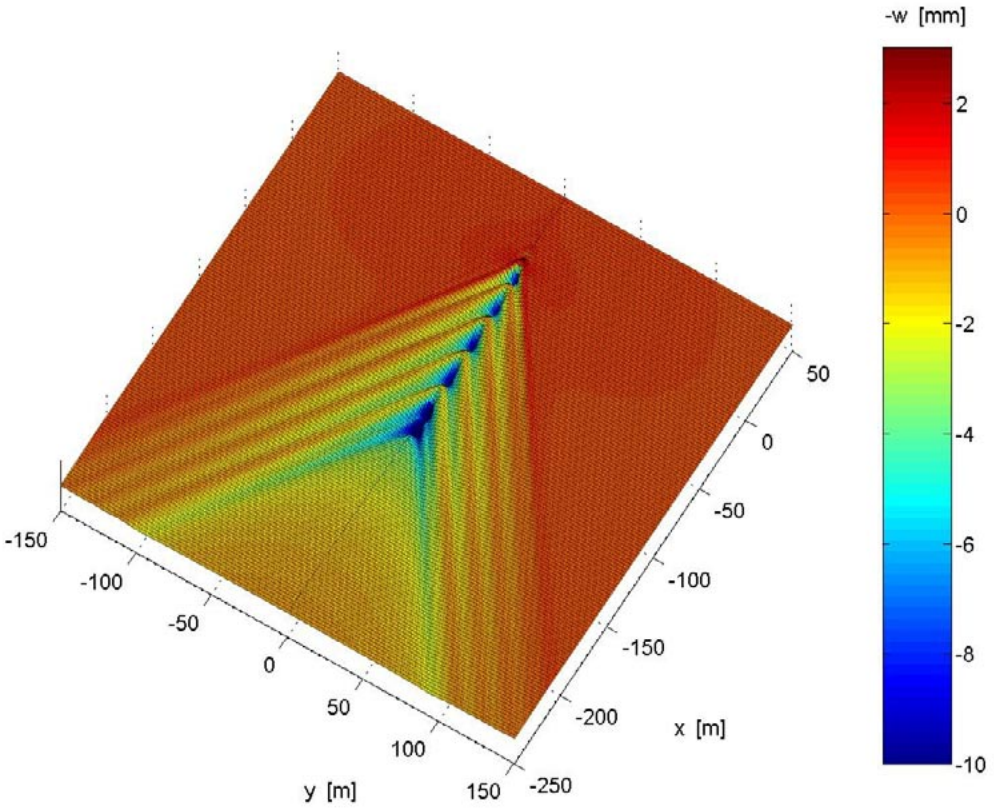
Project leaders and supervisors	Professor Anders Boström and Professor Thomas Abrahamsson, Applied Mechanics
Doctoral candidate	Mr Anders Karlström (from 2002-12-09; Lic Eng October 2004; PhD October 2006)
Period	2002-12-01– 2006-06-30 (– 2006-12-31)
Chalmers budget (excluding university basic resources)	Stage 3: KSEK 500 Stage 4: KSEK 2 050 Stage 5: KSEK 200
Industrial interests in-kind budget	Stage 3: – Stage 4: – Stage 5: –

For a photo of Thomas Abrahamsson, see page 28

In project VB8, refined models of the ground vibrations caused by a train passage have been established using simple analytical descriptions of sleepers and rails on a viscoelastic embankment resting on a layered viscoelastic ground. The models are linear and permit the use of advanced Fourier techniques to find solutions in the frequency domain. This means less flexibility compared to a finite element (FE) model but will result in much faster computations and also displays the vibrational field at all positions. To increase the functionality, an FE model of the track and/or a building can be coupled to the analytical model. Counter-measures to combat ground vibrations are being sought. 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.

The full model (infinitely extended) considers a layered ground, a layered embankment and trenches on one or both sides of the track. The sleepers are modelled as a continuous anisotropic Kirchhoff plate (with zero stiffness along the railway) and the rails as Euler-Bernoulli beams. Groups of forces (the weight of the train) travel on the beams. The forces may accelerate or decelerate. Parametric studies have been performed. The layering of the embankment has made it possible to study different vibration attenuation devices. For frequencies below 30 Hz, an installed concrete slab significantly reduces the vibrations whereas a rubber layer has practically no effect.

Results for supersonic train speeds show that trenches have a large positive effect on the attenuation of ground vibrations on the outer side of the trench. For subsonic speeds the effect is smaller. The crucial parameter is the depth of the trench; a depth of at least three metres should be used. It may not be realistic to dig and maintain



Example in project VB8 of calculated ground vibration as caused by an X2 train travelling at the constant speed 200 km/h. The embankment with the track (not visible in the picture) rests on a semi-infinite clay body, taken as homogeneous and linear viscoelastic, with shear wave speed 148 km/h (41 m/s). The vertical displacement pattern shown in the picture is quasi-static which means that it travels along with the train and is seen as static by an observer on board the train. The maximum displacement is 14 mm and occurs under the heavy motor coach (here pushing the train). The model can also handle an accelerating or braking train

VB8. (cont'd)

Dr Anders Karlström (left; doctorate earned in October 2006) and his supervisor Professor Anders Boström in project VB8. The screen displays the calculated vibrational field on the ground surface from a loaded wheelset travelling at supersonic speed relative to the shear wave speed in the ground. There is a trench on one side of the railway. Compare with the example on the previous page where no trenches are used

such a trench along a railway line, but a similar result can be expected by using a vertical soft mattress. The present analytical model has been integrated with the numerical model in DIFF3D, see project TS8. The difficulty was that DIFF3D works in the time domain whereas the analytical model works in the frequency domain.

Anders Karlström gave his licentiate seminar on 21 October 2004 with Dr Amir Kaynia of the Norwegian Geotechnical Institute (NGI) introducing the discussion. On 13 October 2006 Anders Karlström successfully defended his doctoral dissertation, see below. The faculty-appointed external examiner of the dissertation was Professor Andrei Metrikine from the Faculty of Civil Engineering and Geosciences at Delft Technical University in the Netherlands. The reference group of project VB8 consisted of representatives from Banverket, KTH Soil and Rock Mechanics and NGI.

Anders Karlström: An analytical model for ground vibrations from accelerating trains, *Proceedings 8th International Workshop in Railway Noise (IWRN8),* Buxton, Derbyshire (UK), September 2004, vol 1, pp 85-96

Anders Karlström: Modelling of ground vibrations from railways using an analytical approach, Licentiate Thesis, *Chalmers Applied Mechanics,* Gothenburg October 2004, 43 pp (summary and two appended papers)

Anders Karlström and Anders Boström: An extended analytical model including a layered embankment to simulate ground vibrations from railway traffic, *Proceedings 2nd International Symposium on Environmental Vibrations – Prediction, Monitoring, Mitigation and Evaluation,* Okayama (Japan) September 2005, pp 303-310

Anders Karlström and Anders Boström: An analytical model for train-induced ground vibrations from railways, *Journal of Sound and Vibration,* vol 292, nos 1-2, 2006, pp 221-241

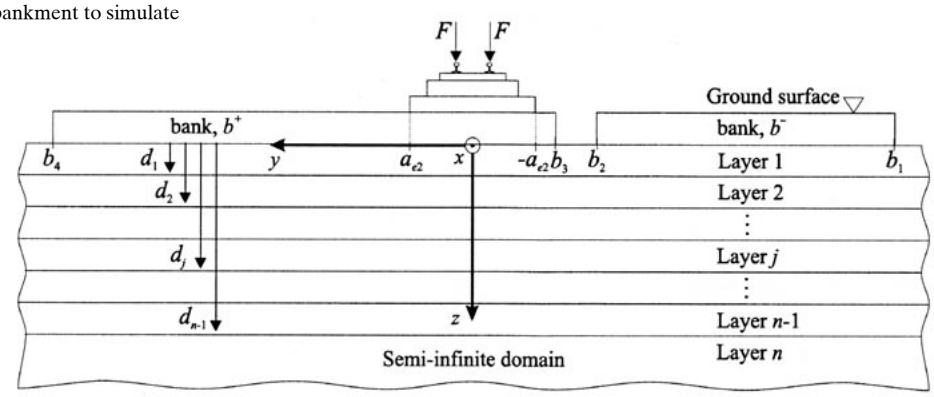
Anders Karlström: An analytical model for ground vibrations from accelerating trains, *Journal of Sound and Vibration,* vol 293, nos 3-5, 2006, pp 587-598 (also presented at *IWRN8,* see above)

Anders Karlström and Anders Boström: On the modelling of trenches as countermeasures to train-induced ground vibration, *Chalmers Applied Mechanics,* Gothenburg 2006 (submitted for international publication)

Anders Karlström, Jens Nielsen and Anders Boström: Train-track-soil numerical-analytical interaction model in the time domain, Research Report 2006:8, *Chalmers Applied Mechanics,* Gothenburg 2006, 22 pp (also listed under project TS8)

Anders Johansson, Jens Nielsen, Rikard Bolmsvik, Anders Karlström and Roger Lundén: Under Sleeper Pads – influence on dynamic train/track interaction, *Proceedings 7th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2006),* Brisbane (Australia) September 2006, vol 2, pp 583-592 (also listed under project TS10)

Anders Karlström: On the modelling of train induced ground vibrations with analytical methods, Doctoral Dissertation, *Chalmers Applied Mechanics,* Gothenburg September 2006, 103 pp (introduction, summary and five appended papers)



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

VB9. DYNAMICS OF RAILWAY SYSTEMS

Dynamik hos järnvägssystem
Dynamik von Eisenbahnsystemen
Dynamique des systèmes de voies ferrées

Project leaders and supervisors	Professor Nils-Erik Wiberg, Applied 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)
Period	2004-07-01 – 2006-06-30 (– 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: –

The overall goal in project VB9 is to provide three-dimensional simulations of the entire railway system. Vehicle, track and underground are modelled as one compound system using the finite element (FE) method combined with rigid-body dynamics. Modern techniques for adaptive mesh generation are being applied. The results will display the dynamic behaviour of the separate components of the system, such as car bodies, bogies, wheels, rails, railpads, sleepers and ballast. Wave propagation in rails, embankment and surrounding ground are studied, in particular for combinations of high train speed and soft clay in the underground. Both tangent and curved track are investigated. Knowledge and skills gained from the finished project VB5 are being utilized.

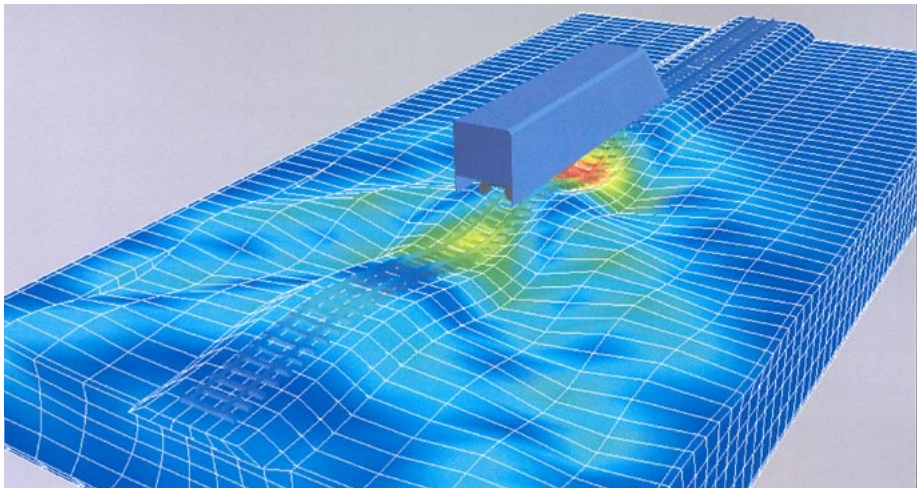
A comprehensive set of simulations with models of three modern high-speed trains (X2, ICE and TGV) has indicated different critical velocities and vibration magnitudes. The design parameters of the trains have a clear influence on the displacement amplitudes of both the track and the surrounding ground. The distance between the bogies seems to be particularly important.

The simulation of a train running over a track section with sloping rock underneath and a decreasing amount of soil on top of the rock has shown that this geometry leads to added wave reflections back to the surface, whereby the vertical vibrations are reduced and their phase content is changed. This situation may be met by a train entering a tunnel. A combination of a long-wave vertical track irregularity (with wavelengths between 5 m and 25 m) and a train speed close to one of the wave propagation speeds in the track/soil structure has been found to result in much higher displacement amplitudes than those from a smooth rail.

The present moving mesh technique has 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 counter-measures in the form of installed lime-cement columns have been studied numerically.

PhD student Håkan Lane (right; licentiate gained in June 2005) and his supervisor Professor Nils-Erik Wiberg in project VB9

VB9. (cont'd)



Calculation window in project VB9 moving with the train (here the X2 power unit). Moving the nodes in the finite element domain together with the train makes better use of computational resources and enables analysis of several phenomena over longer distances. In the example shown, the train speed 250 km/h is close to the Rayleigh wave speed 240 km/h in the ground, whereby strong propagating vibrations are generated

Håkan Lane gave his licentiate seminar on 10 June 2005 with Professor Mats Berg of KTH Railway Group introducing the discussion. According to plans, Håkan Lane will present his doctoral dissertation in May 2007.

Håkan Lane, Torbjörn Ekevid and Nils-Erik Wiberg: Rail induced wave propagation in soil facing sloping rock, *Proceedings 16th Nordic Seminar on Computational Mechanics (NSCM 16) in combination with the Pål G Bergan Anniversary Seminar,* Trondheim (Norway) October 2003, pp 141-144

Håkan Lane, Torbjörn Ekevid and Nils-Erik Wiberg: Towards integrated vehicle-track-underground modelling of train-induced wave propagation, *Book of Abstracts 4th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS2004),* Jyväskylä (Finland) July 2004, vol 1, p 115. Full paper in *Proceedings* on CD, 20 pp

Håkan Lane, Per Kettil and Nils-Erik Wiberg: Modelling train passage in curves with isoparametric differential constraint equations, *Proceedings 17th Nordic Seminar on Computational Mechanics (NSCM 17),* Stockholm (Sweden) October 2004, pp 141-144

Chun-Yuen Ching: Finite element rail vibration dynamics – multi-body dynamics of modern high-speed trains, MSc Thesis 04:15, *Chalmers Structural Engineering and Mechanics,* Gothenburg December 2004, 125 pp

Martin Larsson and Sebastian Berg: Finite element rail vibration dynamics – ground improvement with lime-cement columns, MSc Thesis 05:12, *Chalmers Applied Mechanics,* Gothenburg March 2005, 73 pp

Håkan Lane: Rail vehicle – track structure – subgrade computational analysis – Integrated finite element techniques, Licentiate Thesis, *Chalmers Applied Mechanics,* Gothenburg June 2005, 105 pp (summary and three appended papers)

Håkan Lane, Sebastian Berg and Martin Larsson: Finite element calculations of rail vibration countermeasures, presented at *International Conference on Mathematical Modelling of Wave Phenomena 2005 (MMWP05),* Växjö (Sweden) August 2005

Håkan Lane, Per Kettil, Mikael Enelund, Torbjörn Ekevid and Nils-Erik Wiberg: Absorbing boundary layers for elastic wave propagation, *Proceedings 8th International Conference on Computational Plasticity (COMPLAS 2005),* Barcelona (Spain) September 2005, pp 1087-1090

Per Kettil, Håkan Lane and Nils-Erik Wiberg: The moving mesh adaptation technique – application to train-induced wave propagation. *Proceedings Conference on Adaptive Modeling and Simulation (ADMOS2005 / An ECCOMAS Thematic Conference),* Barcelona (Spain) September 2005, pp 81-91

George Godwin Ogwemoh: Finite element rail vibration dynamics – influence of track irregularities, MSc Thesis 05:79, *Chalmers Applied Mechanics,* Gothenburg December 2005, 106 pp

Torbjörn Ekevid, Per Kettil, Håkan Lane and Nils-Erik Wiberg: Computational railway dynamics, Keynote Lecture delivered at *3rd European Conference on Computational Mechanics (ECCM2006),* Lisbon (Portugal) June 2006. Printed in *Computational Mechanics* (editors C A Mota Soares, J A C Martins, H C Rodrigues and J A C Ambrósio), Springer, Dordrecht 2006, pp 577-598

Håkan Lane, Per Kettil and Nils-Erik Wiberg: Moving mesh adaptivity applied to railway dynamics, Paper 2373 at *3rd European Conference on Computational Mechanics (ECCM2006),* Lisbon (Portugal) June 2006. See Book of Abstracts, Springer, Dordrecht 2006, p 406

Håkan Lane, Torbjörn Ekevid, Per Kettil, Chun-Yuen Ching and Nils-Erik Wiberg: Adaptive multigrid for full scale railway dynamics, *Proceedings 12th International Conference on Computational and Applied Mathematics (ICCAM 2006),* Leuven (Belgium) July 2006, 22 pp (available on CD)

Håkan Lane, Sebastian Berg and Martin Larsson: Finite element calculations of rail vibration countermeasures, *Vehicle System Dynamics* (accepted for publication)

Håkan Lane, Torbjörn Ekevid, Per Kettil, Chun-Yuen Ching and Nils-Erik Wiberg: Integrated vehicle-track-underground modelling of train-induced wave propagation, *Computers & Structures* (accepted for publication)

Håkan Lane, Per Kettil, Mikael Enelund, Torbjörn Ekevid and Nils-Erik Wiberg: Absorbing boundary layers for elastic wave propagation (submitted to *Applied Mathematical Modelling*)

Håkan Lane, Per Kettil and Nils-Erik Wiberg: Moving finite elements and dynamic vehicle interaction (submitted to *European Journal of Mechanics A – Solids*)

VB10. EXTERNAL NOISE GENERATION FROM TRAINS

Dynamik hos järnvägssystem
Dynamik von Eisenbahnsystemen
Dynamique des systèmes de voies ferrées

Project leaders and supervisors	Professor Wolfgang Kropp, Civil and Environmental Engineering, and Dr Anders Frid, Bombardier Transportation Sweden
Doctoral candidate	Ms Astrid Pieringer, Maîtrise en ingénierie, École Polytechnique de Montréal
Period	2006-05-01 – 2006-06-30 (– 2011-04-30)
Chalmers budget (excluding university basic resources)	Stage 4: KSEK 125 Stage 5: KSEK 2 550
Industrial interests in-kind budget	Stage 4: – Stage 5: KSEK 200 *(Bombardier Transportation)*

PhD student Astrid Pieringer and her supervisor Professor Wolfgang Kropp in project VB10. Photo taken in the echo-free laboratory of Chalmers Applied Acoustics

Traffic operators, infrastructure administrators, train manufacturers and society in general all have an interest in the reduction of external noise from railways. For moderate train speeds, the dominating contribution is generated at the contact between wheel and rail. This applies both to the rolling noise and to the squeal noise that may occur on curves. The reasons behind rolling noise and squeal noise relate to the roughness of the contact surfaces and to the frictional properties of these surfaces, respectively.

Today, TWINS is the most widespread software for prediction of the noise that arises from the interaction of wheel and track. The calculations are carried out in the frequency domain which means that only a linearised contact model can be considered and that a contact filter must be defined in order to suppress short-wavelength excitation. A contact model in the time domain, which allows for the inclusion of non-linearities, will be developed, whereby similar methodology can be adopted as in the tyre/road noise group in the present Division of Applied Acoustics. The complete numerical prediction tool, incorporating rolling and squeal noise, will be validated through field measurements. It should be useful as a design tool for the evaluation of modifications of wheel and track with regard to noise reduction. The project will be run in co-operation with project TS11.

Example of an experimental set-up at Chalmers Applied Acoustics which is being used to simulate the sound and vibration properties of a transmission line in a heavy vehicle

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.

The work in the MU1 project has been delayed. Lars Jacobsson has left Chalmers for employment at SP Swedish Testing and Research Institute in Borås. His constitutive ballast model has been applied in the joint SP7 project, reported below. See also the CHARMEC Biennial and Triennial Reports from 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 of the Department of Materials Science and Metallurgy at the University of Cambridge, UK.

In co-operation with the wheel 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 the CHARMEC Triennial Reports from Stages 2 and 3.

Since April 2001, Johan Ahlström has been employed at Chalmers as Assistant Professor in his department (now Materials and Manufacturing Technology) and has been involved in CHARMEC projects MU13, MU15 and MU16, as reported below. For a photo of Johan Ahlström and Birger Karlsson, see page 50.

MU3. MARTENSITE FORMATION AND DAMAGE AROUND RAILWAY WHEEL FLATS

Martensitbildning och skadeutveckling kring hjulplattor
Martensitbildung und Beschädigung an Radplatten
Formation de martensite et dommage aux roues dans les zones de plats

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 was Professor Lennart Karlsson of the Department of Computer Aided Design at Luleå University of Technology, Sweden. Professor Roger Lundén together with Professor Bengt Åkesson of Chalmers Solid Mechanics (now Applied Mechanics) supervised Johan Jergéus' research in project MU3.

PhD student Johan Jergéus (doctorate earned in January 1998) of the MU3 project. Photo taken in 1997

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 FE code. New and better guidelines were proposed for the turning of wheels with wheel flats. See also the CHARMEC Biennial and Triennial Reports from Stages 1, 2 and 3. Continued CHARMEC research in the area of project MU3 is reported in the paper below.

Markus Wallentin, Hans Bjarnehed and Roger Lundén: Cracks around railway wheel flats exposed to rolling contact loads and residual stresses, *Wear,* vol 258, nos 7-8, 2005, pp 1319-1329 (revised article from conference CM2003)

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 was Professor Michael W Brown of 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 the CHARMEC Biennial and Triennial Reports from Stages 1, 2 and 3. See also the MU9 project with continued research in the same area.

Since April 2000, Anders Ekberg has been employed as Assistant Professor at Chalmers Solid Mechanics (now Applied Mechanics) where he has worked in close co-operation with Dr Elena Kabo. In parallel with project MU9, he is now also involved in projects MU10, MU18, EU9, EU10 and SP7, see below. In August 2005, Anders Ekberg was appointed Docent, see page 85. For a photo of Anders Ekberg, see page 42.

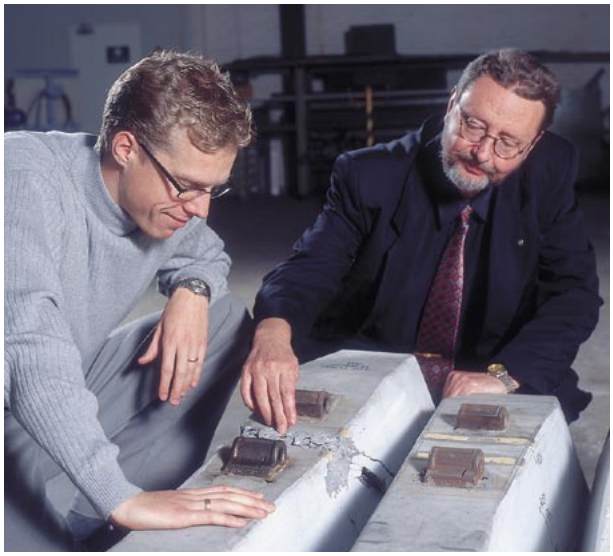
MU5. MECHANICAL PROPERTIES OF CONCRETE SLEEPERS

Mekaniska egenskaper hos betongsliprar
Mechanische Eigenschaften von Betonschwellen
Propriétés mécaniques de 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 of 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. It was found that adhesion was the main bonding mechanism in the initial phase. A change in the strand surface or the concrete recipe that increases adhesion will thus largely improve the anchorage of the prestressing force during the prestressing release in sleeper manufacturing. Full-scale laboratory tests on sleepers showed how different strand designs affect both the prestressing process during the production of sleepers and the response (deformation, crushing and cracking) when the sleepers are subjected to increased loading.

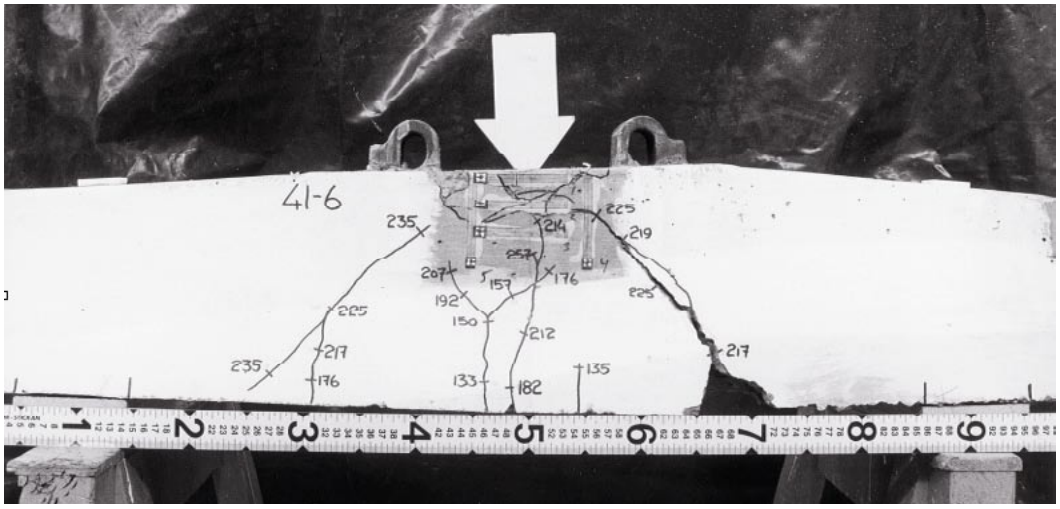
A three-dimensional bonding model for the prestressed strands has been incorporated into the general computer program DIANA for concrete structures. Use of the finite element method (non-linear and three-dimensional) enabled detailed studies revealing how differing design parameters influence the behaviour of a concrete sleeper when installed in the track. In these studies, the in-house computer program DIFF (see under project TS1) was used to generate the operational loading on the sleeper. There was close collaboration with the sleeper manufacturer Abetong Teknik. See also the CHARMEC Triennial Reports from Stages 2 and 3. The articles below have been printed since the latter report was edited. Since December 2002, Rikard Bolmsvik has been employed by Abetong Teknik in Växjö, Sweden.



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 75

Rikard Gustavson: Experimental studies of the bond response of three-wire strands and some influencing parameters, *RILEM Publications – Materials and Structures / Materiaux et Construction,* vol 37, March 2004, pp 96-106

Rikard Gustavson and Karin Lundgren: Modelling of bond between three-wire strands and concrete, *Magazine of Concrete Research,* vol 58, no 3, 2006, pp 123-133



Loading to fracture of a concrete sleeper in project MU5. Photo taken in the laboratory of Chalmers Concrete Structures

MU6. ROLLING CONTACT FATIGUE OF RAILS

Rullkontaktutmattning av järnvägsräl
Ermüdung von Schienen durch Rollkontakt
Fatigue de contact des rails au roulement

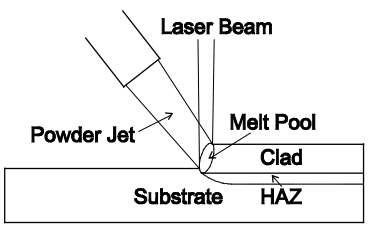
The MU6 project was completed with Jonas Ringsberg's successful defence in public of his doctoral dissertation in September 2000. The title of the dissertation is "Rolling contact fatigue of railway rails with emphasis on crack initiation". The faculty-appointed external examiner of the dissertation was Professor Roderick A Smith of 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.

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 new photo of Lennart Josefson, see page 51

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. The 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.

During the period September 2000 to July 2004, Jonas Ringsberg was employed as Assistant Professor at Chalmers Solid Mechanics. After a period at the Strength and Durability Center of the Volvo Car Corporation he took up a position in November 2005 as Senior Lecturer at the Department of Shipping and Marine Technology at Chalmers. In April 2004, Jonas Ringsberg was appointed Docent, see page 85. See also the CHARMEC Triennial Reports from Stages 2 and 3.

Jonas Ringsberg: Shear mode growth of short surface-breaking RCF cracks, *Wear,* vol 258, nos 7-8, 2005, pp 955-963 (revised article from conference CM2003)



Sketch of cladding process as studied in project MU7. The cladding material is injected into the melt pool by means of an inert gas jet

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. Photo taken in 2003. For a new photo of Niklas Köppen, see page 50

MU7. LASER TREATMENT OF WHEELS AND RAILS

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

Project leader and supervisor	Professor Birger Karlsson, Materials and Manufacturing Technology
Doctoral candidate	Mr Simon Niederhauser (from 2000-04-17; Lic Eng February 2003; PhD December 2005)
Period	2000-01-01–2005-12-31
Chalmers budget (excluding university basic resources)	Stage 2: KSEK 700 Stage 3: KSEK 2 050 Stage 4: KSEK 1 300
Industrial interests in-kind budget	Stage 2: KSEK 200+500+300 *(Adtranz Wheelset+Duroc +Inexa Profil)* Stage 3: KSEK 500+200 *(Duroc + Lucchini Sweden)* Stage 4: KSEK 500+200 *(Duroc Rail + Lucchini Sweden)*

The MU7 project was completed with Simon Niederhauser's successful defence in public of his doctoral dissertation (see below) in December 2005. The faculty-appointed external examiner of the dissertation was Professor Andreas Mortensen of the Laboratory of Mechanical Metallurgy at École Polytechnique Fédérale de Lausanne (EPFL) in Lausanne, Switzerland.

The project aimed at studying the possibility of 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 on a cheaper substrate material, e g onto the railhead on curves. Different powders and process parameters can be used whereby the microstructure and the friction and wear properties of the added layer can be varied. The aim was to find suitable combinations of surface layer and base material in order to improve the fatigue and fracture behaviour of cladded wheels and rails. The project was run in collaboration with Duroc Rail in Luleå, Sweden.

Co-Cr and Fe-Cr alloys were laser-cladded onto railway steel, giving a composite material consisting of the clad, the heat-affected zone (HAZ) and the unaffected substrate. Cladding using the TIG welding process was also applied.

Microstructure analyses were performed on the HAZ and the Co-Cr clad material as well as on the interface between clad and substrate. The HAZ consisted of tempered martensite near the clad, bainite farther away, and a partially transformed zone near the unaffected substrate. The clad consisted of colonies of dendrites in elongated grains, stretching from the interface up to the clad surface. There is a high compositional gradient at the interface. The integrity of the interface is created by dilution of substrate elements into the clad. Hardness measurements from the clad through the HAZ into the unaffected substrate showed smooth transitions. This indicates a smooth transition of other mechanical properties.

Tensile testing of the two composite materials (with Co-Cr and Fe-Cr coatings) demonstrated a high yield strength and a strong work hardening. Both materials exhibited advantageous behaviour in low-cycle fatigue. The number of cycles to failure was comparable to that of the substrate material alone, but with considerably higher applied stresses. Neither of the mechanical tests led to delamination of the clad material. See also the CHARMEC Triennial Reports from Stages 2 and 3.

The reference group of project MU7 consisted of people from the Duroc companies in Luleå and Umeå, Sweden. Simon Niederhauser left Chalmers at the end of December 2005 for a position at the SSAB steelworks in Oxelösund, Sweden.

Simon Niederhauser and Birger Karlsson: Mechanical properties of laser cladded steel, *Materials Science and Technology,* vol 19, no 11, 2003, pp 1611-1616

Simon Niederhauser, Birger Karlsson and Peter Sotkovszki: Microstructural development in the heat-affected zone of a laser-cladded steel, *Zeitschrift für Metallkunde,* vol 96, no 4, 2005, pp 370-376

Simon Niederhauser and Birger Karlsson: Fatigue behaviour of Co-Cr laser cladded steel plates for railway applications, *Wear,* vol 258, nos 7-8, 2005, pp 1156-1164 (revised article from conference CM2003)

Muhammad Irfan Qadeer: Microstructure and mechanical properties of TIG cladded steel plates, MSc Thesis 2006:49, *Chalmers Materials and Manufacturing Technology,* Gothenburg 2006, 51 pp

Simon Niederhauser, Birger Karlsson and Peter Sotkovszki: Microstructural study of a Co-Cr laser clad, *Zeitschrift für Metallkunde* (in print)

Simon Niederhauser, Birger Karlsson and Peter Sotkovszki: Microstructure and fatigue properties of a Fe-12.5% Cr laser cladded steel plate, *Materials Science and Technology* (in print)

Simon Niederhauser: Interface between a laser clad and its substrate, *Chalmers Materials and Manufacturing Technology* (to be published)

Simon Niederhauser: Laser cladded steel – microstructures and mechanical properties of relevance for railway applications, Doctoral Dissertation, *Chalmers Materials and Manufacturing Technology,* Gothenburg December 2005, 128 pp (introduction, summary and seven appended papers)

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 (see below) in September 2004. The faculty-appointed external examiner of the dissertation was Professor Fredrick V Lawrence Jr, of the Department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign, USA. Professor Lennart Josefson of Chalmers Applied Mechanics supervised Anders Skyttebol's research.

In Banverket's stationary installation at Sannahed in Sweden, flash butt-welding is applied to produce longer rail units. In the track, thermite welding is used for the final joining of these units. The welding process can affect the mechanical properties of the rails in two ways. Firstly,

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 new photo of Lennart Josefson, see page 51

residual stresses from the welding interact with stresses from the operational load on the track (global fatigue load and local contact load). This influences the sensitivity to initiation of rolling contact fatigue cracks and thus the need for rail maintenance. Secondly, deformations in the weld joint affect the straightness of the rails and thus the running dynamics of the trains.

A detailed three-dimensional numerical simulation of the electrical, thermal and mechanical fields during flash butt-welding has been performed. 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 with the welding process have been carried out at Sannahed. A microstructural assessment of flash butt-welded rail specimens, including tensile tests and measurements of hardness and fracture toughness (Charpy-V), has been made.

The growth of fatigue cracks from defects at the rail weld has been studied for a specific loading case on Malmbanan (the Iron Ore Line in northern Sweden with axle load 30 tonnes and train speed 50 km/h) where information on contact forces was available. The redistribution of welding residual stresses and the growth of fatigue cracks from defects in the rail weld have been simulated. The time period for the growth of cracks from a size detectable by ultrasonics to a critical size has been estimated.

The reference group of project MU8 included representatives from Banverket and (up to October 2001) Inexa Profil. In June 2004, Anders Skyttebol recommenced his work at the Volvo Aero Corporation in Trollhättan, Sweden. See also the CHARMEC Triennial Report from Stage 3.

Kenneth Runesson, Anders Skyttebol and Lars-Erik Lindgren: Nonlinear finite element analysis and applications to welded structures, in *Comprehensive Structural Integrity* (editors R de Borst and H A Mang), Elsevier, Oxford 2003, vol 3: Numerical and Computational Methods, pp 255-320

Anders Skyttebol: Models for high temperature recovery in welding simulations, Research Report 2004:9, *Chalmers Applied Mechanics,* Gothenburg 2004, 15 pp

Anders Skyttebol, Peter Sotkovszki, Lennart Josefson and Hans Johansson: Microstructural evaluation and mechanical properties of the welded zone in flash butt welded rails (submitted to *Science and Technology of Welding & Joining*)

Anders Skyttebol and Lennart Josefson: Numerical simulation of flash-butt-welding of railway rails, in *Mathematical Modelling of Weld Phenomena 7 – Proceedings 7th International Seminar on Numerical Analysis of Weldability* (editors H Cerjak, H K H Bhadesa and E Kozeschnik), TU Graz Publishing, Graz (Austria) 2004, pp 943-964

Anders Skyttebol, Lennart Josefson and Jonas Ringsberg: Fatigue crack growth in a welded rail under the influence of residual stresses, *Engineering Fracture Mechanics,* vol 72, no 2, 2005, pp 271-285

Anders Skyttebol: Continuous welded railway rails – residual stress analyses, fatigue assessments and experiments, Doctoral Dissertation, *Chalmers Applied Mechanics,* Gothenburg September 2004, 219 pp (introduction, summary and six appended papers)

Jonas Ringsberg, Anders Skyttebol and Lennart Josefson: Investigation of the rolling contact fatigue resistance of laser cladded twin-disc specimens: FE simulations of laser cladding, grinding and a twin-disc test, *International Journal of Fatigue,* vol 27, no 6, 2005, pp 702-714 (also listed under project EU7)

MU9. ROLLING CONTACT FATIGUE OF RAILWAY WHEELS

Rullkontaktutmattning av järnvägshjul
Ermüdung von Eisenbahnrädern durch Rollkontakt
Fatigue de contact des roues ferroviaires au roulement

Project leaders	Docent Anders Ekberg and Dr Elena Kabo, Applied Mechanics
Co-worker	Professor Roger Lundén, Applied Mechanics
Doctoral candidate	None (only senior researchers in this project)
Period	2000-07-01–2006-06-30
Chalmers budget (excluding university basic resources)	Stage 3: kSEK 1 350+200 Stage 4: kSEK 1 000
Industrial interests in-kind budget	Stage 3: kSEK 200+200 *(Bombardier Transportation +Lucchini Sweden)* Stage 4: kSEK 75 *(Lucchini Sweden)*

For photos of Anders Ekberg, Elena Kabo and Roger Lundén, see pages 42 and 58

The safety of railway wheels and their life-cycle costs are dependent on phenomena associated with the rolling contact stresses in the rim of the wheels. The fatigue life of a wheel is linked to factors such as load magnitude, material quality, material anisotropy, material defects and manufacturing processes and also plastic deformations in operation. Relevant and complete material specifications should consider the mechanical properties of possible material defects and also their form, size and physical location.

The overall aim of the MU9 project was to develop an "engineering" approach to rolling contact fatigue analysis while taking into account the factors mentioned above. The model should be useful in the design of the wheel geometry and when making an optimum choice of wheel material and maintenance intervals. Several meetings have been held with Bombardier Transportation, Deutsche Bahn, Duroc Rail, Lucchini Sweden, MTAB, Spoornet, Interfleet Technology and others for project discussions. There has also been co-ordination with projects MU10 and EU6.

Based on WLIFE, see under project MU4, the computer program FIERCE (Fatigue Index Evaluator for Rolling Contact Environments) has been 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. Surface-initiated fatigue is assessed using shakedown theory. Subsurface-initiated fatigue is evaluated using a multiaxial fatigue criterion. Analytic expressions have been established for the fatigue impact, allowing very fast calculations.

The underlying theory and the FIERCE program are being refined and updated continuously. Developments during the current Stage 4 include an evaluation of the influence of single and clustered defects of varying size and location, and the development and implementation of a fracture mechanics-based fatigue index for deep material defects. Updated versions of FIERCE are being provided continuously to Bombardier Transportation and other industrial partners.

Apart from the direct development of FIERCE, its integration with analysis of dynamic train/track interaction and additional advanced FE simulations has also been improved. Such studies have significantly increased knowledge of the effects of rail corrugation and insulated joints on rolling contact fatigue and plastic deformations. These studies have been performed together with Jens Nielsen of project TS8 and are featured in the in-house code DIFF.

Studies within MU9 have provided increased knowledge of the (lack of) abilities of current criteria for the classification of hollow wear on the running surface of wheels along with an in-depth understanding of the mechanisms behind the detrimental nature of hollow wear. In addition, benefits, challenges and possibilities when using bainitic wheel steels have been explored.

The joint reference group for projects MU9 and MU10 includes representatives from Bombardier Transportation Sweden and Interfleet Technology. Anders Ekberg has assisted Bombardier Transportation, Lucchini Sweden, MTAB (an operator on the Iron Ore Line) and others in resolving various fatigue problems for wheels and axles (see references below).

Anders Ekberg, Elena Kabo and Hans Andersson: Answer to a letter to the editor from M Ciavarella and H Maitournam, *Fatigue & Fracture of Engineering Materials & Structures,* vol 27, no 6, 2004, pp 527–528

Jens Nielsen, Anders Ekberg, Elena Kabo and Roger Lundén: Integrated analysis of dynamic train–track interaction and rolling contact fatigue, *Proceedings 14th International Wheelset Congress,* Orlando Florida (USA) October 2004, 15 pp (available on CD. Also listed under project TS8)

Anders Ekberg: Report on flange wear of timber wagons in Sweden, *Chalmers Industriteknik (CIT),* Gothenburg August 2004, 9 pp (availability restricted)

MU9. (cont'd)

Elena Kabo and Anders Ekberg: Material defects in rolling contact fatigue of railway wheels – the influence of defect size, *Wear,* vol 258, nos 7-8, 2005, pp 1194-1200 (revised article from conference CM2003)

Anders Ekberg and Elena Kabo: Fatigue of railway wheels and rails under rolling contact and thermal loading – an overview, *ibidem,* pp 1288-1306 (revised article from conference CM2003)

Anders Ekberg: Report on multiaxial fatigue evaluation of railway axles, *Chalmers Applied Mechanics,* Gothenburg 2005, 5 pp (availability restricted)

Anders Ekberg: Hjulskador på papperstransportvagnar (Wheel damage on freight wagons for paper; in Swedish), *Chalmers Applied Mechanics,* Gothenburg 2005, 13 pp (availability restricted)

Jens Nielsen, Anders Ekberg and Roger Lundén: Influence of short-pitch wheel/rail corrugation on rolling contact fatigue, *IMechE Journal of Rail and Rapid Transit,* vol 219, no F3, 2005, pp 177–187 (also listed under projects TS8 and SP11). In July 2006, this paper obtained the *IMechE Railway Division W A Agnew / C N Goodall Award 2005*

Elena Kabo, Jens Nielsen and Anders Ekberg: Prediction of dynamic train/track interaction and subsequent material deterioration, *Three Page Abstracts 19th IAVSD Symposium,* Milan (Italy) August– September 2005, 3 pp (available on CD. Also listed under project TS8)

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* (in press. Also listed under projects TS8 and SP8)

Robert Fröhling, Anders Ekberg and Elena Kabo: Developing hollow wear limits based on field experience and numerical simulations, *Proceedings 7th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2006),* Brisbane (Australia) September 2006, vol 2, pp 599-607

Tord Karlsson, Andrea Ghidini, Andrea Gianni and Anders Ekberg: Innovative bainitic steel grade for solid wheels tested in arctic heavy haul operations, *Proceedings 7th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2006),* Brisbane (Australia) September 2006, vol 1, pp 303-308

Anders Ekberg, Tore Vernersson and Roger Lundén: Iron Ore Line, Kiruna, Sweden: Risk of cracking of locomotive wheels due to very high thermal brake powers, *Chalmers Applied Mechanics,* Gothenburg 2006, 21 pp (availability restricted)

Tore Vernersson and Anders Ekberg: Iron Ore Line, Kiruna, Sweden: Comparison of field measurements with numerical simulations, *Chalmers Applied Mechanics,* Gothenburg 2006, 5 pp (availability restricted)

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 Elena Kabo and Docent Anders Ekberg, Applied Mechanics
Doctoral candidate	Ms Eka Lansler (from 2002-02-01 to 2005-03-31; Lic Eng January 2005)
Period	2002-02-01–2006-06-30 (–2007-06-30)
Chalmers budget (excluding university basic resources)	Stage 3: kSEK 1 100 Stage 4: kSEK 2 050 Stage 5: kSEK 300
Industrial interests in-kind budget (Lucchini Sweden)	Stage 3: kSEK 400 Stage 4: kSEK 100 Stage 5: kSEK 100

Cracks in dynamically loaded metal structures are usually unavoidable. One design philosophy is to ensure that these cracks are detected before any of them have reached a critical size that may endanger safe operations. This requires predictive models of how rapidly a crack grows in the structure and under what conditions complete structural failure will occur. The aim of project MU10 is to establish suitable crack growth and fracture models for railway wheels. In particular, cracks initiated below the tread surface should be studied, bearing in mind that such cracks grow in a multiaxial and essentially compressive stress field with rotating principal directions.

Finite element (FE) simulations have been performed to evaluate stresses and strains at a subsurface crack during a wheel revolution. The model has been verified for evaluation of the K_{II} stress intensity factor (shear mode) under small-scale yielding conditions. The simulations consider both elastic and elastoplastic material. Numerical

MU10. (cont'd)

implementation of a multiaxial low-cycle fatigue criterion (developed in project MU9) has been modified to suit the current study. The influence of residual stresses from plastic deformations on stress intensities at the crack tip has been studied. The J-integral was discarded as a suitable measure to characterize subsurface crack propagation in railway wheels. Instead, a K_{II}-based criterion and a criterion directly based on stress and strain in front of the crack tip have been chosen. In FE simulations, both elastic and elastoplastic stresses and strains around a subsurface crack during a wheel revolution can now be evaluated, and the robustness of the developed model has been proven.

It has been found that the influence on crack propagation by operationally induced residual stresses as well as by plastic deformations during a load passage (a wheel revolution) is small. Consequently, it has been made likely that methods based on linear elastic fracture mechanics (LEFM) are applicable to the current problem. The importance of operational parameters, such as load magnitude and contact geometry, has been investigated and documented. As for operations on corrugated tracks, the influence of several parameters on the rolling contact fatigue (RCF) impact has also been evaluated. For high-speed trains, it was found that the increase in contact forces (as opposed to poor contact geometry) is the main reason behind increased fatigue impact. For operations on severely corrugated tracks, the wheel mass was found to have practically no influence and the axle load only a limited influence on RCF.

The joint reference group for projects MU9 and MU10 consists of representatives from Bombardier Transportation Sweden and Interfleet Technology. Eka Lansler presented her licentiate thesis (see below) at a seminar on 12 January 2005, where Professor Ulf Stigh of the University of Skövde, Sweden, acted as discussion initiator. Eka Lansler left Chalmers at the end of March 2005. A revised research plan dated 22 June 2005 is now being followed in project MU10. In conjunction with project MU10, Roger Lundén has developed and reported an analytical model for subsurface elastoplastic crack propagation based on a Dugdale approach, see final reference below.

Eka Lansler: Subsurface rolling contact fatigue cracks in railway wheels – elastoplastic deformations and mechanisms of propagation, Licentiate Thesis, *Chalmers Applied Mechanics,* Gothenburg December 2004, 60 pp (summary and two appended papers)

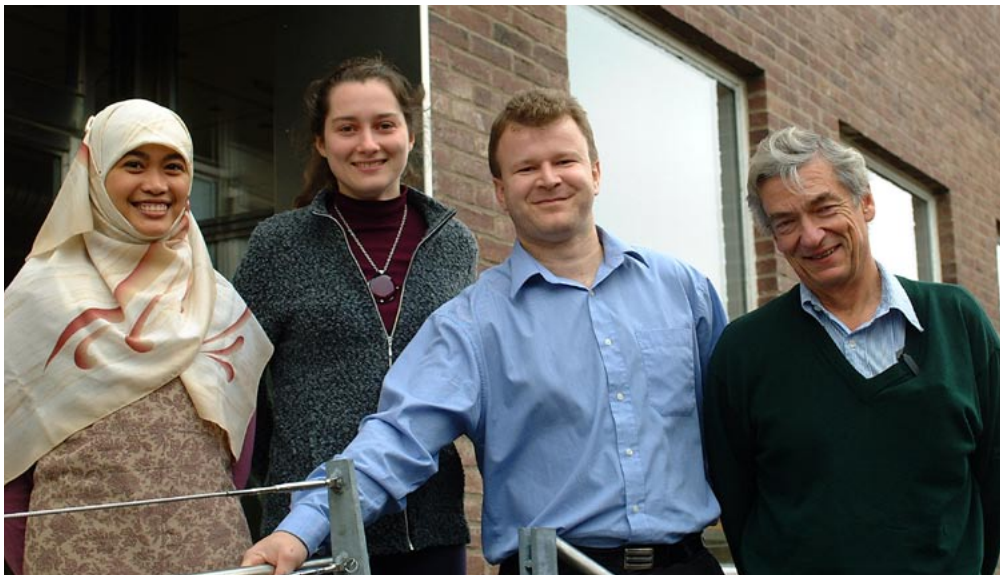
Eka Lansler and Elena Kabo: Sub-surface crack face displacements in railway wheels, *Wear,* vol 258, nos 7-8, 2005, pp 1038-1047 (revised article from conference CM2003)

Alejandro Martinez: Cross-sectional cracks in rails – evaluation of stress intensity factors, MSc Thesis 2006:16, *Chalmers Applied Mechanics,* Gothenburg 2006, 47 pp

Eka Lansler, Anders Ekberg, Elena Kabo and Hans Andersson: The influence of plastic deformations on growth of subsurface rolling contact fatigue cracks in railway wheels, *IMechE Journal of Rail and Rapid Transit* (accepted for publication)

Anders Ekberg, Elena Kabo, Jens Nielsen and Roger Lundén: Subsurface initiated rolling contact fatigue of railway wheels as generated by rail corrugation, *Chalmers Applied Mechanics,* Gothenburg 2006 (submitted for international publication. Also listed under project TS8)

Roger Lundén: Elastoplastic modelling of subsurface crack growth in rail/wheel contact problems, *Fatigue & Fracture of Engineering Materials & Structures* (accepted for publication)



PhD student Eka Lansler (left; licentiate gained in January 2005) and her supervisors Professor Hans Andersson (right), Dr Elena Kabo and Docent Anders Ekberg in project MU10. Photo taken in 2003. For a new photo of Anders Ekberg, see page 51

MU11. EARLY CRACK GROWTH IN RAILS

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

Project leaders and supervisors	Professor Lennart Josefson, Doc Jonas Ringsberg (up to 2004-08-31) and Professor Kenneth Runesson (from 2004-12-01), Applied Mechanics
Doctoral candidate	Mr Anders Bergkvist (from 2001-12-03 to 2005-06-30; Lic Eng June 2005)
Period	2001-12-01–2005-12-31
Chalmers budget (excluding university basic resources)	Stage 3: KSEK 1 050 KSEK 250 *(voestalpine Schienen)* Stage 4: KSEK 1 175
Industrial interests in-kind budget	Stage 3: KSEK 50 *(Inexa Profil)* Stage 4: KSEK 600 *(voestalpine Bahnsysteme)*

The aim of the MU11 project was to develop numerical models for the simulation and prediction of the growth of surface cracks (head checks) once they have been initiated on the railhead. The simulation models should be useful when planning preventive rail maintenance, e g determining grinding intervals and grinding depths. A numerical method should be developed to predict when, how (direction) and how rapidly a pre-defined 0.3-0.5 mm deep surface crack (head check) grows in a given traffic situation and in a given external environment.

A parametrized two-dimensional finite element (FE) model with a surface crack and a rolling contact load has been established. Elastic (linear) and elastoplastic (non-linear) analyses have been carried out to study how the fracture conditions around the crack tip are affected by plasticity. Non-linear fracture mechanics has been adopted. Wear is 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) has been pursued. The main advantage of this concept is that it is valid for elastic as well as inelastic material response. The computation of material forces has been done in a post-processing step after the calculation of the necessary

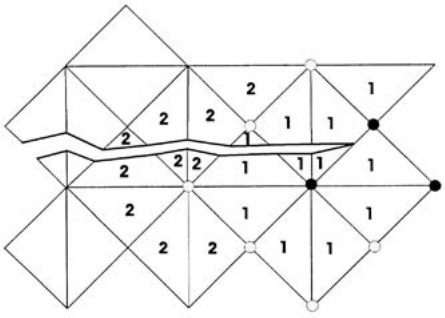
PhD student Anders Bergkvist (left; licentiate gained in June 2005) and his supervisor Doc Jonas Ringsberg in project MU11. Photo taken in 2003. For a photo of Lennart Josefson, see page 39

strain and internal variable fields using the commercial code ABAQUS. A technique has been developed to map solution variables from an "uncracked" FE model to an FE model containing a crack. The behaviour of a crack in a plastically deformed material during a discrete number of cycles, e g 1, 10, 25, 50, 100 etc, can thus be investigated.

No formal reference group was established for project MU11 although the ideas and achievements have been discussed continuously with Banverket in Sweden and with voestalpine Schienen and other contacts abroad. Anders Bergkvist presented his licentiate thesis (see below) on 9 June 2005 with Dr Erland Johnson of SP Swedish Testing and Research Institute introducing the discussion. Anders Bergkvist left Chalmers at the end of June 2005 for employment elsewhere. Project MU17 can be seen as a partial continuation of project MU11.

Anders Bergkvist: On the crack driving force in elastic-plastic fracture mechanics with application to rolling contact fatigue in rails, Licentiate Thesis 2005:20, *Chalmers Applied Mechanics,* Gothenburg June 2005, 73 pp (including one appended paper)

Johan Tillberg: Computation of the crack-driving force in elastic-plastic materials – a comparative study, MSc Thesis 2005:65, *Chalmers Applied Mechanics,* Gothenburg December 2005, 44 pp



Example of calculated mixed mode crack propagation through a finite element mesh in project MU12

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

Project leader and supervisor	Professor Peter Hansbo, Applied Mechanics
Doctoral candidate	Mr Per Heintz (from 2001-11-01; Lic Eng December 2003; PhD September 2006)
Period	2001-11-01–2006-06-30 (–2006-10-31)
Chalmers budget (excluding university basic resources)	Stage 3: KSEK 625 Stage 4: KSEK 1 025 Stage 5: KSEK 125
Industrial interests in-kind budget	Stage 3: KSEK 50 *(Inexa Profil)* Stage 4: KSEK 450 *(voestalpine Bahnsysteme)* Stage 5: KSEK 50 *(voestalpine Bahnsysteme)*

Note: MU12 has been financed partly by the Chalmers Finite Element Center

Numerical finite element (FE) techniques have been developed to predict when and how a pre-defined crack in a rail will grow under given loading conditions. The usual node-to-segment contact algorithms are avoided since they are lacking in accuracy and stability. Instead, Lagrange multipliers (stabilized) have been employed to enforce zero penetration and a balance of forces at the interface between wheel and rail. Both linear elastic fracture mechanics (LEFM) and non-linear fracture mechanics (NLFM) are applied. Adaptive FE calculations have been 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, see figure on page 43. Results from the parallel project MU11 have been employed.

The main tool utilized in the present work is a set of Fortran module packages developed within the project. They are written in Fortran 90/95 and use the full extent of the standard in order to obtain a highly modularized environment. The packages have been successfully compiled in both Windows and Linux operating systems. Different compilers have been used. The modules are used together as a computing engine and wrappers to external software have been developed. Support for commercial software has been implemented. It is possible to import meshes and export results from and to the codes ABAQUS and LS-DYNA.

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

Per Heintz successfully defended his doctoral dissertation (see below) in public on 28 September 2006. The faculty-appointed external examiner was Professor Paul Steinmann of the Department of Mechanical and Process Engineering at Technische Universität Kaiserslautern, Germany. See also the CHARMEC Triennial Report from Stage 3.

Per Heintz and Peter Hansbo: A discontinuous Galerkin method for crack propagation, *Book of Abstracts 4th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2004),* Jyväskylä (Finland) July 2004, vol II, p 461 (full paper available on CD)

Per Heintz and Klas Samuelsson: On adaptive strategies and error control in fracture mechanics, *Computers & Structures,* vol 82, no 6, 2004, pp 485-497

Per Heintz, Fredrik Larsson, Peter Hansbo and Kenneth Runesson: Adaptive strategies and error control for computing material fores in fracture mechanics, *International Journal for Numerical Methods in Engineering,* vol 60, no 7, 2004, pp 1287-1299

Per Heintz and Peter Hansbo: Stabilized Lagrange multiplier methods for bilateral contact with friction, *Computer Methods in Applied Mechanics and Engineering,* vol 195, nos 33-36, 2006, pp 4323-4333 (also presented at *8th US National Congress on Computational Mechanics,* Austin TX (USA) July 2005)

Per Heintz: On the numerical modeling of quasi-static crack growth in linear elastic fracture mechanics, *International Journal for Numerical Methods in Engineering,* vol 65, no 2, 2006, pp 174-189

Peter Hansbo and Per Heintz: Finite element modeling of cohesive cracks by Nitsche's method, presented at *16th European Conference on Fracture (ECF16),* Alexandropoulos (Greece) July 2006. Abstract in *Fracture of Nano and Engineering Materials and Structures* (editor E E Gdoutos), Springer, Berlin 2006, p 947 (full paper available on CD)

Per Heintz: Finite element procedures for the numerical simulation of crack propagation and bilateral contact, PhD Dissertation, *Chalmers Applied Mechanics,* Gothenburg September 2006, 103 pp (introduction, summary and five appended papers)

MU13. WHEEL AND RAIL MATERIALS AT LOW TEMPERATURES

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

Project leaders	Dr Johan Ahlström, Assistant Professor, and Professor Birger Karlsson, Materials and Manufacturing Technology
Period	2001-07-01–2006-06-30
Chalmers budget (excluding university basic resources)	Stage 3: kSEK 1 000 Stage 4: kSEK 1 000
Industrial interests in-kind budget (Lucchini Sweden)	Stage 3: kSEK 100 Stage 4: kSEK 200

For a photo of Johan Ahlström and Birger Karlsson, see page 50

Railway wheels and rails are steel components exposed to high stresses. In general, steel has substantially inferior mechanical properties at low temperatures than at normal temperature. In the MU13 project, the influence of operating temperatures down to –40°C on fatigue and fracture behaviour has been studied. As for the influence of different loading rates on the flow behaviour, this can be simulated by using different testing temperatures. High loading rates in service at –40°C could thus be simulated by slow rig testing at –60°C. For this purpose, low-temperature testing equipment mounted on a servo-hydraulic fatigue testing rig has been built and used. Procedures to enable monotonic and cyclic tensile tests to be performed at low temperatures have been elaborated. Several tests have been run at –60°C, –20°C and 20°C.

In the previous project MU2, wheels made of several different materials were manufactured in full scale. All did conform to the ER7T standard, but the manufacturing procedure was altered to achieve a more fine-grained microstructure than the reference material. In the present project, the low-cycle fatigue behaviour at low temperatures has been examined for the most promising of the materials from MU2. The best of the modified (fine-grained) materials had considerably better fatigue properties at –60°C than the reference material. However, in comparison with low temperature tests performed on the pearlitic steel grade ER8T, the number of cycles to failure is generally lower for all ER7T materials, but this is believed to be true only for un-notched specimens. Experiments with quasi-static pre-straining up to 5 % preceding the cyclic loading indicate that the fatigue life becomes considerably shorter at low temperatures. This is in contrast to the influence of pre-straining at room temperature.

As reported previously, the fatigue properties of the pearlitic rail steel UIC900A have been studied under both stress and strain controlled conditions. Stress-strain loop shapes, hardening/softening, fatigue life and the influence of tensile mean stresses on ratchetting have been investigated for test bars taken from a commercial rail. As regards the low-cycle fatigue behaviour of the rail steel UIC900A at room temperature, softening was found to take place during the initial part of the life and to be most evident at low strain amplitudes.

The work in the present project has been co-ordinated with that in project MU16. The joint reference group of projects MU13 and MU16 had members from Lucchini Sidermeccanica (Italy) and Bombardier Transportation Sweden. See also the CHARMEC Triennial Report from Stage 3.

Michael Mirsch: Low cycle fatigue behaviour of railway wheel steel, MSc Thesis 34/2003, *Chalmers Materials Science and Engineering,* Gothenburg 2003, 94 pp. This work was awarded Swedtrain's (Swedish Association of Railway Industries) Prize 2004 for the Best Master's Thesis in Railway Technology

Johan Ahlström, Birger Karlsson and Michael Mirsch: Low cycle fatigue behaviour of railway wheel steels including temperature effects, *Proceedings 11th International Conference on Fracture (ICF11),* Turin (Italy) March 2005, 6 pp (available on CD)

Johan Ahlström and Birger Karlsson: Fatigue behaviour of rail steel – a comparison between strain and stress controlled loading, *Wear,* vol 258, nos 7-8, 2005, pp 1187-1193 (revised article from conference CM2003)

Göran Johansson, Johan Ahlström and Magnus Ekh: Parameter identification and modeling of large ratcheting strains in carbon steel, *Computers & Structures,* vol 84, nos 15-16, 2006 (also listed under project MU14)

Alexander Timmer: Investigation of the microstructure and temperature impact on the low cycle fatigue behaviour of a medium carbon, low alloyed railway wheel steel, Project report, *Chalmers Materials and Manufacturing Technology,* Gothenburg 2006, 62 pp

Johan Ahlström and Birger Karlsson: The fatigue properties of modified railway wheel steels as influenced by low temperature and grain size, *Proceedings 9th International Fatigue Congress,* Atlanta Georgia (USA) May 2006, 10 pp (available on CD)

Niklas Köppen, Johan Ahlström and Birger Karlsson: Static and cyclic behaviour of near fully pearlitic railway steel – influence of temperature and prestrain, *ibidem,* 8 pp (available on CD. Also listed under project MU16)

MU14. DAMAGE IN TRACK SWITCHES

Skador i spårväxlar
Schäden an Weichen
Détérioration des aiguilles

Project leaders and supervisors	Docent Magnus Ekh, Senior Lecturer, and Professor Kenneth Runesson, Applied Mechanics
Doctoral candidate	Mr Göran Johansson (from 2002-08-01; Lic Eng June 2004; PhD September 2006)
Period	2002-08-01–2006-06-30 (–2007-06-30)
Chalmers budget (excluding university basic resources)	Stage 3: KSEK 500 KSEK 150+150 *(VAE+voestalpine Schienen)* 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 Teknikenheten + voestalpine Bahnsysteme)* Stage 5: KSEK 100 *(voestalpine Bahnsysteme)*

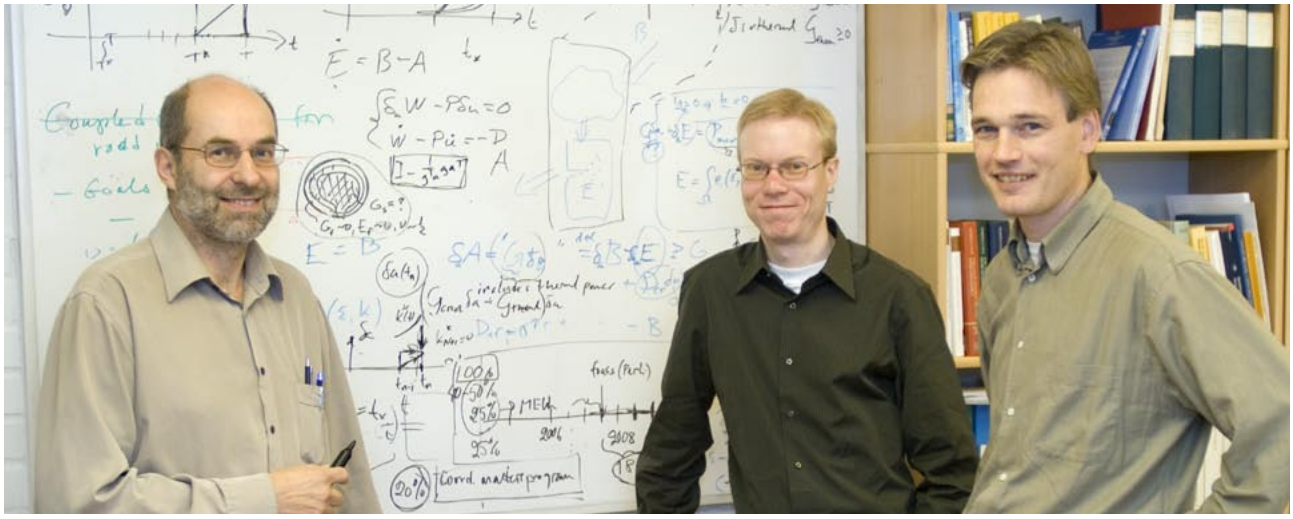
The Swedish railway network contains approximately ten thousand track switches (turnouts). Defects registered during track inspections by Banverket are very often related to these switches and similar tendencies are reported outside Sweden by other railway administrations. The MU14 project aims to provide a fundamental basis for the development of track switches which permit longer inspection intervals, have fewer faults at inspection, involve lower maintenance costs, and cause less disruption in rail traffic. Two components subjected to severe loading conditions are the switch blade and the crossing nose, see figure under project TS7.

Sketches of (a) initial pearlitic microstructure with randomly oriented grains, (b) deformed microstructure, and (c) induced texture on the macroscopic length scale

Geometry changes in a turnout will eventually result in discontinuities in the rolling contact between wheel and rail, giving rise to increased wheel/rail contact loads. A special geometry change, which is common on curves and turnouts, is denoted lipping. This is the rolling out of the material on the crown of a rail towards the sides of the head.

Mathematical modelling and simulation of large deformations and damage in switch components 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 pearlitic steel. The performance of the models has been illustrated in numerical examples and in comparisons with field measurements.

MiniProf measurements of the dimensions of the crossing nose (made of manganese steel) have been made on



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

MU14. (cont'd)

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. The research was carried out in cooperation with the turnout manufacturer VAE in Austria and with the Department of Materials and Manufacturing Technology at Chalmers.

One part of the work of predicting large irreversible deformations in railway components has considered the two-phase structure of pearlitic carbon steel where each grain has a preferred direction that is determined by its cementite lamellae. After large shearing and compressive deformation, the orientations of individual grains tend to align with each other and anisotropy evolves on the macroscopic level. The work has focused on the development of a physically realistic model for the evolution of anisotropy on the macroscopic length scale, see figure. See also the CHARMEC Triennial Report from Stage 3.

Göran Johansson successfully defended his doctoral dissertation (see below) in public on 29 September 2006. The faculty-appointed external examiner of the dissertation was Professor Bob Svendsen of the Department of Mechanical Engineering at the University of Dortmund (Germany). Göran Johansson had gained his Licentiate of Engineering degree in June 2004. The TS7 and MU14 projects have a joint reference group, see under TS7.

Göran Johansson: Constitutive modeling of large ratcheting strains in carbon steel, Licentiate Thesis, *Chalmers Applied Mechanics,* Gothenburg June 2004, 62 pp (introduction, summary and two appended papers)

Göran Johansson and Alexander Santos: Measurements of geometry changes in railway turnout components, Research Report 2005:7, *Chalmers Applied Mechanics,* Gothenburg 2005, 12 pp

Göran Johansson: Simulation of damage in railway turnout components, Research Report 2005:8, *Chalmers Applied Mechanics,* Gothenburg 2005, 15 pp

Göran Johansson and Magnus Ekh: Modeling of large ratcheting strains with large time increments, *Proceedings 8th International Conference on Computational Plasticity (COMPLAS2005),* Barcelona (Spain) September 2005, pp 763-765

Göran Johansson, Magnus Ekh and Kenneth Runesson: Computational modelling of inelastic large ratcheting strains, *International Journal of Plasticity,* vol 21, no 5, 2005, pp 955-980

Göran Johansson and Magnus Ekh: On the modeling of large ratcheting strains with large time increments, *Engineering Computations* (accepted for publication)

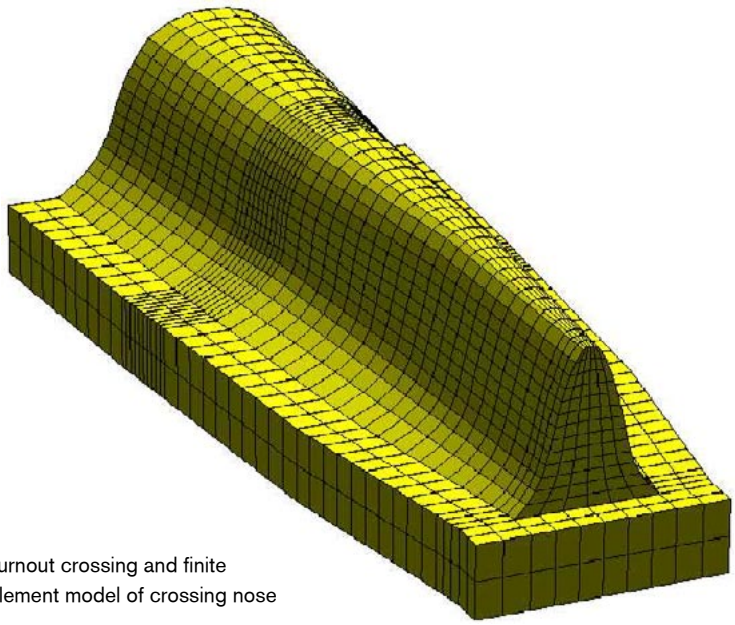
Göran Johansson, Andreas Menzel and Kenneth Runesson: Modeling of anisotropic inelasticity in pearlitic steel at large strains due to deformation induced substructure evolution, *European Journal of Mechanics – A/Solids,* vol 24, no 6, 2005, pp 899-918

Göran Johansson, Johan Ahlström and Magnus Ekh: Parameter identification and modelling of large ratcheting strains in carbon steel, *Computers & Structures,* vol 84, nos 15-16, 2006, pp 1002-1011 (also listed under project MU13)

Göran Johansson and Magnus Ekh: On the modelling of evolving anisotropy and large strains in pearlitic steel, *European Journal of Mechanics – A/Solids,* vol 25, no 6, 2006, pp 1041-1060

Göran Johansson: On the non-oscillation criterion for multiplicative anisotropic plasticity at large simple shear deformation, *Chalmers Applied Mechanics,* Gothenburg 2006 (to be submitted for international publication)

Göran Johansson: On the modeling of large ratcheting strains and anisotropy in pearlitic steel, Doctoral Dissertation, *Chalmers Applied Mechanics,* Gothenburg September 2006, 169 pp (introduction, summary and five appended papers)



Turnout crossing and finite element model of crossing nose

MU15. MICROSTRUCTURAL DEVELOPMENT DURING LASER COATING

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

Project leader	Professor Birger Karlsson and Dr Johan Ahlström, Assistant Professor, Materials and Manufacturing Technology
Doctoral candidate	None (only senior researchers in this project)
Period	2001-07-01–2003-09-30 and 2005-07-01–2006-06-30
Chalmers budget (excluding university basic resources)	Stage 3: KSEK 600 Stage 4: KSEK 700
Industrial interests in-kind budget	Stage 3: KSEK 150 *(Duroc Rail)* Stage 4: KSEK 450 *(Duroc Rail)*

For a photo of Birger Karlsson and Johan Ahlström, see page 50

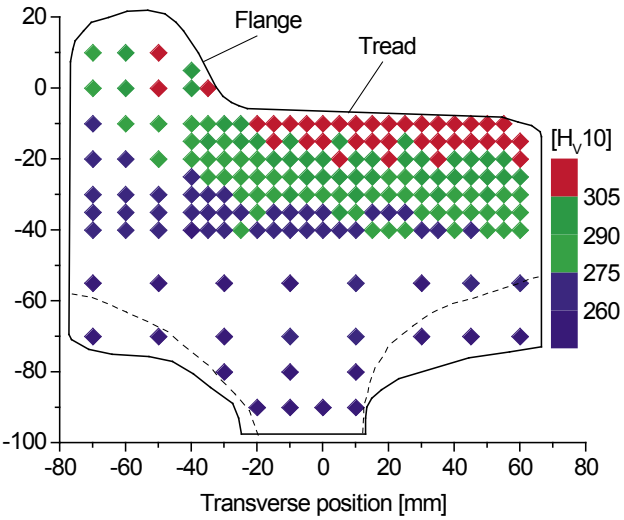
Railway wheels and rails are steel components which interact via direct contact. The tribological properties in the contact area can be improved by replacing one of the materials. One way of doing this is to coat either the wheel tread or particularly exposed parts of the railhead with Co-Cr using a laser-based method. During the coating process, the underlying steel is heated and then cooled rapidly, resulting in the creation of a so-called heat-affected zone (HAZ). The aim of project MU15 has been to find optimum microstructures and properties of the coating and the HAZ so that the life-span of wheels and rails will be maximized.

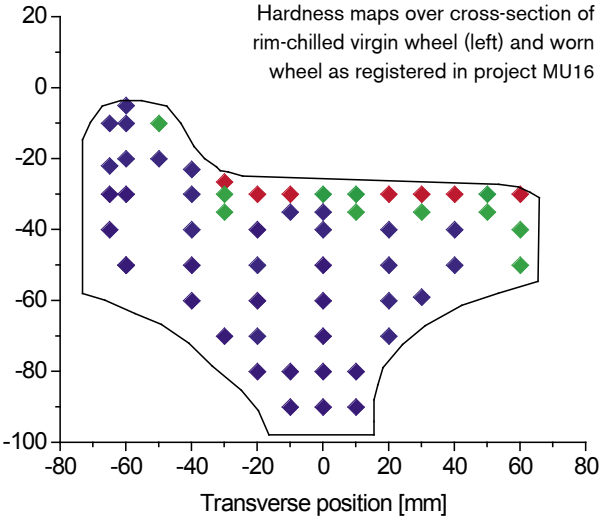
Some thirty specimens of the wheel material SURA B82 (corresponding to ER7) and five specimens of the rail material UIC900A have been hardened and polished and thereafter exposed to thermal treatment with the laser technique developed at Laserzentrum Leoben in Austria. Between 100 and 200 hardness indents per sample have been made to map the cross-sections, which have also been studied using microscopy. A finite element model of the development of the temperature field during the laser treatment has been established and numerical simulations have been performed to further the extraction of more information from the tests.

The present laser-pulse technique enables isothermal treatments of a duration down to a few milliseconds. This has been found to be a general technique with outstanding performance for studies of material response after thermal treatments. The laser experiments gave mutually coherent results. However, in comparison with earlier experiments performed in salt baths, there are differences requiring further studies. See also the CHARMEC Triennial Report from Stage 3.

Peter Krahl: Short time tempering behaviour of martensite in steel, Project Thesis 25/2004, *Chalmers Materials Science and Engineering,* Gothenburg 2004, 45 pp

Johan Ahlström, Birger Karlsson and Simon Niederhauser: Modelling of laser cladding of medium carbon steel – a first approach, *Journal de Physique IV,* vol 120, 2005, pp 405-412





Hardness maps over cross-section of rim-chilled virgin wheel (left) and worn wheel as registered in project MU16

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, Assistant Professor, and Professor Birger Karlsson, Materials and Manufacturing Technology
Doctoral candidate	Mr Niklas Köppen (from 2003-10-01; Lic Eng November 2006)
Period	2003-03-01–2006-06-30 (–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)*

For a photo of Johan Ahlström, Birger Karlsson and Niklas Köppen, see the next page

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 or internal or external defects etc. This calls for more damage-tolerant base materials. The aim of project MU16 is to study and develop alternative materials/microstructures with regard to fatigue strength under varying conditions, the most important one being high strain rates and/or low temperatures where embrittlement may appear.

Investigations have been performed on a batch of wheels with material specification UIC R8T delivered by Lucchini Sidermeccanica in Italy. Test pieces were cut out near the wheel tread. Tensile testing was performed in a wide temperature range from –60°C to +180°C with determination of strain rate effects and deformation hardening as well as ductility. Fatigue testing was carried out at constant strain amplitudes (half of peak-to-peak) up to 1%, again at room temperature and at –60°C as well as at +100°C. The final fracture was mainly ductile at room temperature but gradually shifted over to partly brittle at –60°C. The change in life-span (N_f) at decreased temperature was found to depend on the total strain amplitude. N_f thus increased with decreasing temperatures at low strain amplitudes while it decreased at high strain amplitudes. The experimental results exhibited a very low experimental scatter, e g the scatter in fatigue life was less than 15% in all tests. Static pre-straining was found to considerably shorten the fatigue life. Charpy V testing revealed a gradual decrease in the impact energy from about 25 J at room temperature down to 8 J at –60°C.

A study of the influence of rim chilling showed a systematic variation in hardness through the wheel cross-section with higher values close to the tread, see figure. This results in similar differences in how flow stresses are maintained during the whole fatigue process. The hardness also decreases when approaching the flange of the wheel. This should be considered when producing test samples and also in the evaluation of fatigue data and in modelling.

A general observation of practical importance in testing is that flow stress levels are increased when the temperature is decreased or when the strain rate is increased. Since the material reaction is identical, higher strain rates observed in service can be simulated by decreasing the temperature in laboratory tests. An increased strain rate by a factor of 100 can thus be simulated through a decrease in temperature of about 10°C. Complementary tests performed on R8 and R8T steel grades further supported previous findings and have enabled a better interpretation of experimental results.

Niklas Köppen presented his licentiate thesis (see below) at a seminar on 10 November 2006 with Professor Jens Bergström of Materials Engineering at Karlstad University (Sweden) introducing the discussion.

The joint reference group of projects MU16 and MU13 includes members from Bombardier Transportation Sweden, Lucchini Sidermeccanica (Italy) and VAE (Austria). See also the CHARMEC Triennial Report from Stage 3.

Niklas Köppen, Johan Ahlström and Birger Karlsson: Static and cyclic behaviour of near fully pearlitic railway steel – influence of temperature and prestrain, *Proceedings 9th International Fatigue Congress (IFC9),* Atlanta Georgia (USA) May 2006, 8 pp (available on CD. Also listed under project MU13)

Niklas Köppen and Birger Karlsson: Tensile deformation behaviour of near fully pearlitic steels at various temperatures and strain rates, 17 pp (submitted to *Metallurgical and Materials Transactions A*)

Niklas Köppen: Deformation behaviour of near fully pearlitic railway steels during monotonic and cyclic loading, Licentiate Thesis, *Chalmers Materials and Manufacturing Technology,* November 2006, 66 pp (introduction, summary and two appended papers)

MU17. ELASTOPLASTIC CRACK PROPAGATION IN RAILS

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

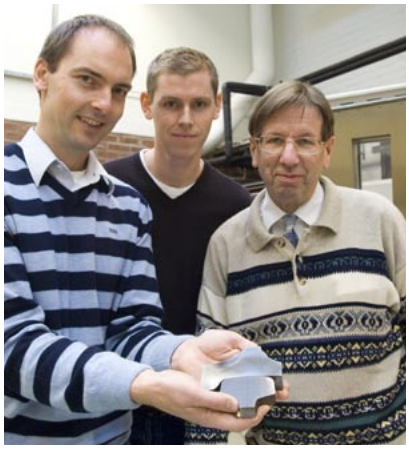
Project leaders and supervisors	Professor Kenneth Runesson, Dr Fredrik Larsson, Assistant Professor, and Professor Lennart Josefson, Applied Mechanics/ Division of Material and Computational Mechanics
Doctoral candidate	Mr Johan Tillberg, MSc (from 2005-12-01)
Period	2005-12-01 – 2006-06-30 (–2010-11-30)
Chalmers budget (excluding university basic resources)	Stage 4: KSEK 500 Stage 5: KSEK 2 350
Industrial interests in-kind budget	Stage 4: KSEK 200 *(voestalpine Bahnsysteme)* Stage 5: KSEK 300 *(voestalpine Bahnsysteme)*

For photos of Kenneth Runesson and Lennart Josefson, see pages 46 and 51

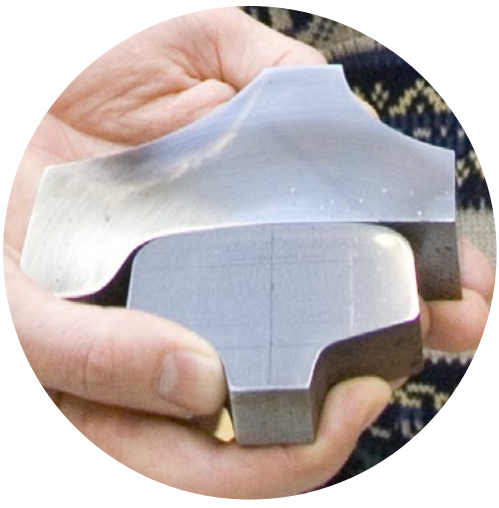
This project may be considered as a continuation of project MU11 but with more focus on resolving some basic issues before dealing with applications. An in-depth investigation will be undertaken of models and methods in elastoplastic fracture mechanics in the presence of truly large plastic deformations. Such conditions are highly relevant for the early propagation of head checks in rails. Key tasks are: (i) establishment of the crack-driving force (generalized J-integral), (ii) efficient finite element computation of the crack-driving force, (iii) modelling of the crack extension due to fatigue loading, and (iv) calibration and validation of the modelling and computation of fatigue crack propagation rates in collaboration with CHARMEC partners. A project plan dated 19 September 2005 was approved by the CHARMEC Board on 6 October 2005.

PhD student Johan Tillberg (left) and his supervisor Dr Fredrik Larsson in project MU17

A model for viscous crack propagation in an elastic stress and strain field has been implemented. Preliminary investigations of multiple crack propagation for simulating prevailing cracks (head checks on rails) has been carried out. An evolution law for crack propagation under cyclic loading (in terms of material force) is being developed. The study of multiple crack propagation will be extended to fatigue loading. Work has been initiated on how to formulate the crack-driving force in an elastoplastic stress and strain field, thereby extending the state-of-the-art of the thermodynamical foundation of material forces (as a prerequisite for future computer implementation).



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



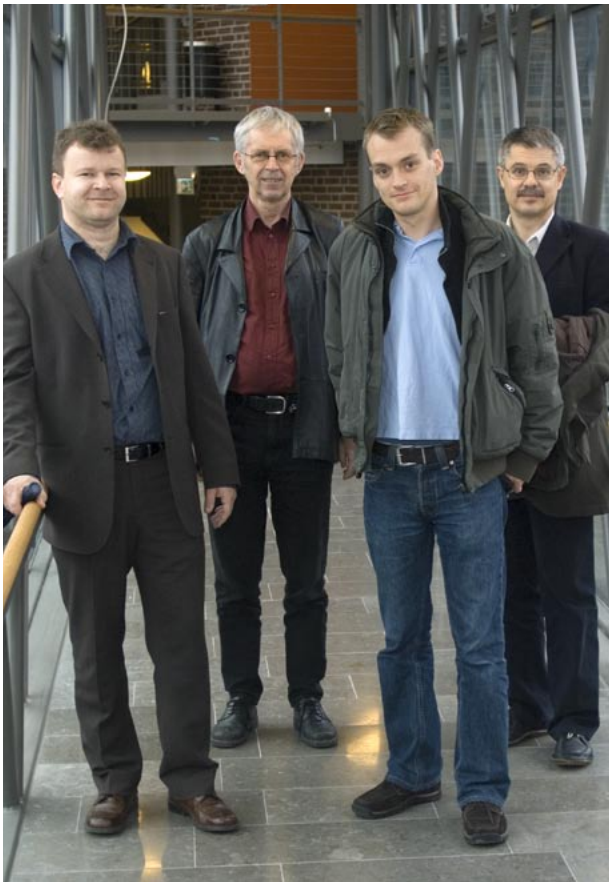
MU18. WHEELS AND RAILS AT HIGH SPEEDS AND AXLE LOADS

Hjul och räls vid höga hastigheter och axellaster

Räder und Schienen bei hohen Geschwindigkeiten und Achslasten

Roues et rails à grande vitesse et charge d'essieu

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, MSc (from 2006-04-18)
Period	2006-04-18 – 2006-06-30 (–2011-04-18)
Chalmers budget (excluding university basic resources)	Stage 4: kSEK 375 Stage 5: kSEK 2 550
Industrial interests in-kind budget	Stage 4: – Stage 5: kSEK 200+100+200 *(Banverket+Bombardier Transportation+Lucchini Sweden)*



PhD student Johan Sandström (second from right) in project MU18 together with his supervisors Docent Anders Ekberg (left), Professor Jacques de Maré (second from left) and Professor Lennart Josefson

Today plans exist in Sweden to increase both the highest permitted speeds and the highest permitted axle loads on the country's railways. As has been acquired through previous experience, this involves technical challenges which are due largely to specific Swedish conditions: (i) the number of potential passengers in high-speed operations as compared with distances travelled is relatively low, a fact which calls for low-cost solutions where high-speed trains are operating 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. Consequently, if speeds and axle loads are to be increased, there is a considerable need to be able to predict what the consequences will be. Furthermore, if problems arise there is a need to quickly find and implement counter-measures. This calls for an understanding of damage mechanisms, an identification of root causes and a quantification of what gains that can be obtained from different counter-measures.

Project MU18 aims to derive knowledge and validated numerical tools and find innovative solutions to render possible the development of tracks in Sweden for higher speeds and axle loads. It focuses on topics that have been identified as cost drivers and includes aspects that prevent internationally found solutions (if such exist) from being directly applicable to Swedish conditions. Topics that will be 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) influence of switches and crossings on wheels under the same conditions. The present work will benefit from several previous and parallel CHARMEC projects. It will follow the application to the Swedish research agency VINNOVA dated 14 September 2005 (with a revision due to the decreased budget).

The initial focus in project MU18 has been on probabilities of rail breaks on the Iron Ore Line in northern Sweden, which was selected because of the well-defined operational characteristics prevailing on that line. Simulations using the in-house code DIFF have been carried out where time histories and magnitude distributions of rail-bending moments due to passing wheels with a flat have been derived. The influence of varying wheel flat geometries and impact positions has been studied.

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 aiguilles

Project leader and supervisor	Docent Magnus Ekh, Senior Lecturer, Applied Mechanics / Division of Material and Computational Mechanics
Assistant supervisors	Professor Kenneth Runesson and Dr Fredrik Larsson, Applied Mechanics
Doctoral candidate	To be recruited
Period	Five years from the start of project
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 1 700
Industrial interests in-kind budget	Stage 5: kSEK 100+50+100 *(Banverket+SL Technology +voestalpine Bahnsysteme)*

For photos of the researchers in MU19, see pages 46 and 50

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 and MU14 will be utilized.

MU20. WEAR IMPACT ON RCF OF RAILS

Nötningens inverkan på rullkontaktutmattning av räler

Einfluss des Verschleisses auf Rollkontaktermüdung von Schienen

Influence de l'usure sur fatigue sous charge roulante des rails

Project leader and supervisor	Professor Kenneth Runesson, Applied Mechanics / Division of Material and Computational Mechanics
Assistant supervisors	Dr Fredrik Larsson and Docent Magnus Ekh, Applied Mechanics
Doctoral candidate	To be recruited
Period	Five years from the start of project
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 1 700
Industrial interests in-kind budget	Stage 5: kSEK 100+50+100 *(Banverket+SL Technology +voestalpine Bahnsysteme)*

For photos of the researchers in MU20, see pages 46 and 50

The interaction of wear and rolling contact fatigue (RCF) of rails will be studied. In the first part of the project, wear will be assumed a priori and its influence on surface initiated RCF be investigated. Crack truncation, changed contact geometry and redistributed residual stresses because of wear will be studied and calibrated against experimental data. In the second part, a refined model for rail profile updating to be used in conjunction with wear prediction will be developed. This model should be of vital importance in integrated vehicle dynamics simulations. The new project MU20 will draw on several previous CHARMEC projects such as TS5, MU4, MU11 and MU12.

MU21. THERMAL IMPACT ON RCF OF WHEELS

Termisk inverkan på rullkontaktutmattning av hjul
Thermische Wirkung auf Rollkontaktermüdung von Rädern
Effet thermique sur la fatigue de roulement des roues

Project leader and supervisor	Docent Anders Ekberg, Applied Mechanics / Division of Material and Computational Mechanics
Assistant supervisors	Dr Elena Kabo, Docent Magnus Ekh and Dr Tore Vernersson, Applied Mechanics
Doctoral candidate	To be recruited
Period	Five years from the start of project
Chalmers budget (excluding university basic resources)	Stage 5: kSEK 1 700
Industrial interests in-kind budget	Stage 5: kSEK 100+200+100 *(Bombardier Transportation +Green Cargo+SweMaint)*

For photos of the researchers in MU21, see pages 42, 46 and 58

The project aims at an improved model for predicting surface-initiated rolling contact fatigue (RCF), including the influence of elevated temperature. During tread braking and disc/electric braking, with or without additional friction from curving, thermal power will be imposed on the surface layer of the wheel tread. This 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 the predictive model. The new project MU21 will draw on previous and parallel CHARMEC projects, such as MU4, MU9, MU10, MU19 and MU20.

MU22. IMPROVED CRITERION FOR SURFACE INITIATED RCF

Förbättrat kriterium för ytinitierad rullkontaktutmattning
Verbessertes Kriterium der oberflächeninitierten Rollkontaktermüdung
Critère amélioré de la fatigue de roulement initié en surface

Project leader	Docent Anders Ekberg, Applied Mechanics / Division of Material and Computational Mechanics
Co-workers	Dr Elena Kabo and Professor Roger Lundén, Applied Mechanics
Doctoral candidate	None (only senior researchers in this project)
Period	2007-07-01–2010-06-30
Chalmers budget (excluding university basic resources)	Stage 5: To be decided
Industrial interests in-kind budget	Stage 5: kSEK 100+200+100 *(Bombardier Transportation +Lucchini Sweden+SweMaint)*

For photos of the researchers in MU22, see pages 42 and 58

In the CHARMEC project MU9, an engineering model to predict rolling contact fatigue (RCF) was derived and named FIERCE (Fatigue Index Evaluator for Rolling Contact Environments). The cracks dealt with in FIERCE are initiated at the surface, below the surface and at deep material defects. The new project MU22 focuses on surface initiated cracks, the treatment of which is considered to be the part of FIERCE in most need of improvement. Existing experimental data from laboratories and the field will be exploited. The present project will draw on the parallel projects MU19, MU20 and MU21.

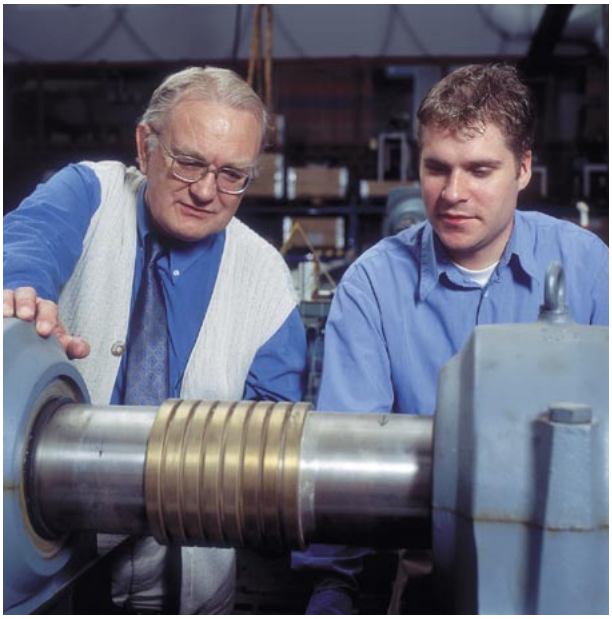
SD1. BRAKING OF FREIGHT TRAINS – A SYSTEMS APPROACH

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

Project leader and supervisor	Professor Göran Gerbert, Machine and Vehicle Design (now Applied Mechanics)
Doctoral candidate	Mr Daniel Thuresson (from 1998-12-01; Lic Eng May 2001; PhD October 2006)
Period	1998-12-01 – 2006-06-30 (–2006-10-31)
Chalmers budget (excluding university basic resources)	Stage 2: kSEK 1 400 Stage 3: kSEK 1 300 Stage 4: kSEK 500+250+150
Industrial interests in-kind budget	Stage 2: kSEK 400+100 *(Cardo Rail+SJ Teknik)* Stage 3: kSEK 250 *(SAB WABCO)* Stage 4: kSEK 180+200 *(Green Cargo+SAB WABCO/ Faiveley Transport)*

Wheels and brakes share a considerable burden of the maintenance costs for tread-braked freight wagons. Higher speeds and increased axle loads have placed greater demands on the brakes. Of special importance are the thermal and mechanical properties (fatigue, wear, friction etc) at the interface between brake block and wheel. The limits of brake performance under varying conditions are of great concern for both manufacturers and users of freight wagons. Project SD1 was aimed at describing the interaction between block and wheel by using simple (but physically correct) models. Critical parameters should be identified. From a theoretical as well as an experimental perspective, little has so far been known about the location, magnitude and distribution of pressure and temperature between sliding bodies. This is especially true when considering high-energy sliding contacts, as found in brakes and clutches.

Photo of a cast iron brake block in operation on the test rig at Surahammar in project SD1



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 Chalmers Machine and Vehicle Design laboratory

Investigations into how various parameters influence contact pressure and temperature have been carried out. The phenomenon known as ThermoElastic Instability (TEI), which is frequently observed in experiments, 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 on next page. In the present project, a two-dimensional finite element model and a one-dimensional pin model were used to calculate interface pressure and temperature, to illuminate essential aspects of a braking system and, coupled with numerical results, to quantify the effects of the properties of different materials. The models can handle temperature-dependent friction and wear coefficients. The less complex pin model of a brake was employed to reduce the computational effort.

Temperature measurements on the full-scale Lucchini/ CHARMEC brake test rig at Surahammar were performed

SD1. (cont'd)

in order to verify the mathematical models. Both measurements and simulations showed an unstable temperature distribution. Comparison of results from the pin model with those from experiments and the finite element model demonstrated that the pin model may be an alternative to more complex models for studying contact pressure, temperature and thermoelastic instability in a sliding contact.

Cast iron brake blocks were found to be more prone to TEI than blocks made of sinter and composition materials. The material parameters with the greatest influence on the development of TEI were the coefficient of thermal expansion, the coefficient of wear, and the specific heat. See also the CHARMEC Triennial Reports from Stages 2 and 3.

Daniel Thuresson successfully defended his doctoral dissertation (see below) in public on 6 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).

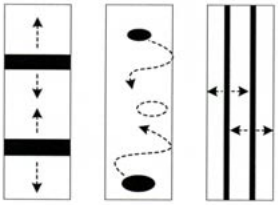
In June 2001, Daniel Thuresson had a serious accident and has since then been on sick leave alternating with working part-time. The SD1 project has therefore been delayed in relation to the original research plan. The reference group of project SD1 consisted of representatives of Faiveley Transport and Green Cargo.

Daniel Thuresson: Influence of material properties on sliding contact braking applications, *Wear,* vol 257, nos 5-6, 2004, pp 451-460

Daniel Thuresson: Stability of sliding contact – comparison of a pin and a finite element model, *Wear,* vol 261, nos 7-8, 2006, pp 896-904

Daniel Thuresson: A pin model and full scale testing of a block brake, *Chalmers Applied Mechanics,* Gothenburg 2006, 33 pp (submitted for international publication)

Daniel Thuresson: Thermomechanics of block brakes, Doctoral Dissertation, *Chalmers Applied Mechanics,* Gothenburg October 2006, 156 pp (introduction, summary and four appended papers)

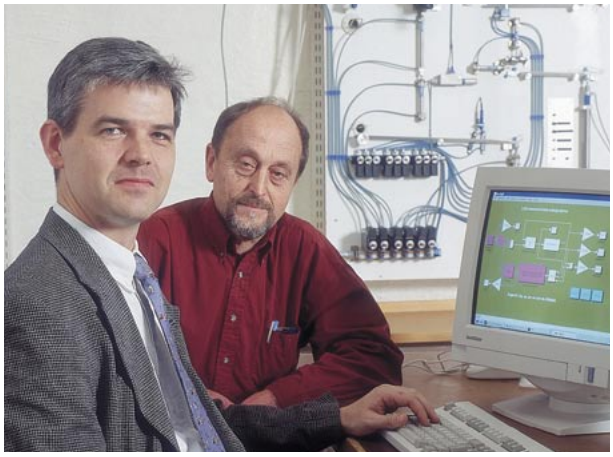


Sketches of the shape and size of moving contact areas on a sliding brake block when ThermoElastic Instability (TEI) occurs. Contact pressure and temperature are high over the black areas

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 the CHARMEC Triennial Report from Stage 2. Acoustic communication/sonar transmission through the main brake line of a trainset (modulation of the pressure signal) were 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 1 200 m in length at SAB WABCO's (now Faiveley Transport) brake system simulator in Piossasco, Italy, as well as on stationary and rolling freight trains in Sweden. Sensors, actuators and software have been developed. The experiments verified the theoretical/numerical models. The conclusion reached in project SD2 was that it is possible to transmit usable information in the pressurized brake line, 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

SD3. COMPUTER CONTROL OF BRAKING SYSTEMS FOR FREIGHT TRAINS

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

Project leader	Mr Håkan Edler, MSc, Computer Engineering
Supervisor	Professor Jan Torin, Computer Engineering
Doctoral candidate	Mr Roger Johansson (from 1999-10-01 on part-time; Lic Eng before start of project; PhD June 2005)
Period	1998-07-01 – 2004-06-30 (–2005-06-30)
Chalmers budget (excluding university basic resources)	Stage 2: kSEK 300+100 Stage 3: kSEK 1 650 Stage 4: –
Industrial interests in-kind budget	Stage 2: kSEK 250+200 *(Cardo Rail+SJ)* Stage 3: kSEK 250+50 *(SAB WABCO +TrainTech Engineering)* Stage 4: –

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 has been how to achieve a satisfactory level of safety with today's commercially available technology. Ways were found to construct reliable systems with the help of computer software. Methods were developed for verifying the reliability of these systems.

Some of the main results from the full SD3 project are: (i) An architecture has been developed for a node in a distributed control system where the natural redundancy in a railway car with four brakes is used to create the desired redundancy in a control system. Each brake device uses standard components, where a microcontroller receives brake commands from the train system and executes them locally. To achieve high dependability these devices can co-operate, exchange data, and check each other frequently. (ii) A simple and robust electronic system as an add-on to the existing control system has been designed and constructed. The add-on handles data communication and assures the desired dependability. This electronic system communicates data in a small dedicated network between the control systems and in each of them keeps track of all the others. If one microcontroller fails, the electronic system can use data from the other microcontrollers and execute the commands from the train system. (iii) A scheduler for dependable data communication in a time-triggered CAN network has been designed.

Roger Johansson successfully defended his doctoral dissertation (see below) in public on 8 June 2005. The faculty-appointed external examiner of the dissertation was

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

SD3. (cont'd)

Professor Martin Törngren of the Division of Mechatronics in the Department of Machine Design at the Royal Institute of Technology (KTH) in Stockholm, Sweden.

The reference group for project SD3 included members from Faiveley Transport, Green Cargo, Halmstad University (Sweden) and SP Swedish National Testing and Research Institute. See also the CHARMEC Triennial Reports from Stages 2 and 3.

Håkan Sivencrona, Torbjörn Olsson, Roger Johansson and Jan Torin: RedCAN™, simulations of two fault recovery algorithms for CAN, *Proceedings 10th IEEE Pacific Rim International Symposium on Dependable Computing Conference (PRDC2004),* Papeete (Tahiti) March 2004, pp 302-311

Roger Johansson: A fault-tolerant architecture for computer-based railway vehicle brake systems, *IMechE Journal of Rail and Rapid Transit,* vol 218, no F3, 2004, pp 189-201

Roger Johansson and Per Johannessen: GAST – General application development boards for safety critical time-triggered systems, *Proceedings 22nd International System Safety Conference (ISSC22),* Providence RI (USA) August 2004, pp 32-39

Roger Johansson: Time and event triggered communication scheduling for the CAN bus, Report no 17, *Chalmers Lindholmen University (Electrical and Computer Engineering),* Gothenburg September 2004, 37 pp (submitted to *Journal of Network & Computer Applications*)

Roger Johansson: On future computer based train vehicle control systems, 26 pp (submitted to *Transportation Research Part C: Emerging Technologies)*

Roger Johansson and Sverker Steen: An implementation of brake-by-wire in railway cars, 29 pp (submitted to *Journal of Systems Architecture*)

Roger Johansson: On distributed control-by-wire systems for critical applications, Doctoral Dissertation, *Chalmers Computer Science and Engineering,* Gothenburg June 2005, 175 pp (summary and seven appended papers)

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

SD4. CONTROL OF BLOCK BRAKING

Reglering av blockbromsning
Steuerung von Klotzbremsen
Contrôle du freinage à sabot

Project leader and supervisor	Professor Roger Lundén, Applied Mechanics
Doctoral candidate	Mr Tore Vernersson (from 2001-03-01 on part-time; Lic Eng September 1997 in project VB2; PhD June 2006)
Period	2001-03-01 – 2006-06-30
Chalmers budget (excluding university basic resources)	Stage 3: kSEK 1700 Stage 4: kSEK 1300+200+300+600
Industrial interests in-kind budget	Stage 3: kSEK 600+400+50 *(Lucchini Sweden+SAB WABCO +TrainTech Engineering)* Stage 4: kSEK 300+400+700+100 *(Green Cargo + Lucchini Sweden + SAB WABCO/Faiveley Transport + TrainTech Engineering/Interfleet Technology)*

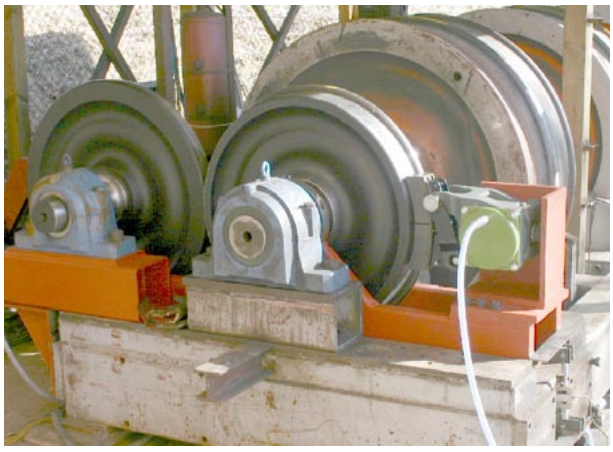


Photo of an experimental test set-up at Surahammar with a tread-braked wheel in rolling contact with the "rail-wheel". One slotted composition block (configuration 1Bg) is used, see page 64

The most common braking system on freight wagons in Europe has tread brakes. The brake blocks may be made of cast iron, composite material or sinter material. The block braking system is relatively cheap and reliable and contributes to good adhesion between wheel and rail due to the roughening of the wheel tread. However, the frictional heat generated can cause damage to the wheel and this is a factor that limits the braking capacity. Another problem is that trains fitted with a block braking system using cast iron blocks radiate much more rolling noise than trains fitted with disc brakes.

SD4. (cont'd)

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

Project SD4 aimed to improve knowledge and control of the heat distribution between block and wheel with a focus on the behaviour of the wheel. Thermal phenomena were studied for various braking histories using both computer simulations and experimental data. Numerical and experimental results obtained in earlier and ongoing work on tread brakes in projects VB2 and EU1 have been utilized. The present work has been co-ordinated with the work in project EU8.

On 8 June 2006, Tore Vernersson successfully defended his doctoral dissertation (see below) in public. 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).

In the first part of Tore Vernersson's work (for the most part done in project VB2), the thermomechanical interaction between brake block and wheel tread was studied to search for the mechanisms behind the growth of wheel roughness. The evolution of hot spots (areas on the wheel tread with a significantly higher temperature than the rest of the tread, cf project SD1) is believed to be a key phenomenon that can explain the behaviour of different block materials. Results from full-scale tread braking experiments with forged wheels on the Lucchini/CHARMEC inertia dynamometer at Surahammar were utilized. A numerical model for studying the thermoelastic contact between brake block and wheel tread demonstrates the principal phenomena. Results from field measurements of wheel roughness are presented and discussed. Hans Johansson, Research Engineer at Chalmers Applied Mechanics, assisted in the Surahammar experiments.

The tendency of cast iron brake blocks to generate high roughness levels on wheel treads has propelled a general shift to other materials which do not generate disturbing roughness levels. However, this change of block material affects the heat partitioning between wheel and block. It was observed that excessive heating of the wheel may cause damage and may 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 initiation and growth of transverse cracks in the wheel rim.

In the second part of Tore Vernersson's work, a thermal model of railway tread braking was developed for use in design calculations of wheel and block temperatures, including the cooling influence from the rail. Brake rig tests have been performed for drag braking at constant brake power for blocks made of cast iron and sinter and composite materials. Results on the influence of block configuration, brake power and brake speed on wheel and block temperatures are reported. Rolling contact heat transfer from wheel to rail (so-called rail chill) is studied in the brake rig using a "rail-wheel" in rolling contact with the braked wheel, along with results from field tests. The model has been calibrated by using data from the experiments and can be employed to calculate temperatures and the heat partitioning between block, wheel and rail. The rail chill is found to have a considerable influence on the wheel temperature for long brake cycles. The present model can be used in the efficient design of tread braking systems for both freight and passenger trains. It can handle stop braking, drag braking at constant brake power, and also intermediate periods of cooling. The temperature history during a full train route can thus be calculated.

A general observation is 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 (e g cast iron or sinter material) will make the axial rim deflections and also the rim temperatures oscillate due to an unstable thermoelastic interaction between block(s) and tread. A more flexible mounting has been found to eliminate these phenomena.

Field test campaigns were run on the Velim test track in the Czech Republic in June 2004 and on the Coal Link in the Republic of South Africa in October 2004. The reference group for project SD4 included members from SAB WABCO/Faiveley Transport and Interfleet Technology.

Roger Lundén, Jürgen Schneider and Tore Vernersson: New wheelsets for 25 and 30 tonne axle loads, *Presentation at 6. Internationale Schienenfahrzeugtagung (RAD Schiene 2003),* Dresden (Germany) October 2003, 6 pp (available on CD)

SD4. (cont'd)

Roger Lundén, Jürgen Schneider and Tore Vernersson: New wheels for 25 and 30 tonne axle loads – design, stresses and geometric stability, *Proceedings 6th International Conference on Railway Bogies and Running Gears (Bogie '04),* Budapest (Hungary) September 2004, pp 265-270

Tore Vernersson and Roger Lundén: Tread braking of railway wheels – wheel and block temperatures and the influence of rail chill, *Proceedings 8th International Heavy Haul Conference (IHHC8),* Rio de Janeiro (Brazil) June 2005, pp 253-260

Tore Vernersson: Block wear and estimated brake power on the Coal Link: Conventional vs BFCB rigging, *Chalmers Applied Mechanics,* Gothenburg 2005, 5 pp (availability restricted)

Tore Vernersson: Temperatures at railway tread braking – Part 1: Modelling, *IMechE Journal of Rail and Rapid Transit* (accepted for publication)

Tore Vernersson: Temperatures at railway tread braking – Part 2: Calibration and numerical examples, *IMechE Journal of Rail and Rapid Transit* (accepted for publication)

Tore Vernersson and Roger Lundén: Temperatures at railway tread braking – Part 3: Wheel and block temperatures and the influence of rail chill, *IMechE Journal of Rail and Rapid Transit* (accepted for publication)

Tore Vernersson: Tread braking of railway wheels – noise-related tread roughness and dimensioning wheel temperatures: field tests, rig measurements and numerical simulations, Doctoral Dissertation, *Chalmers Applied Mechanics,* Gothenburg May 2006, 136 pp (introduction, summary and six appended papers)

The brake test rig (inertia dynamometer) in Surahammar at its inauguration in 1989. From left: Roger Lundén; Josef Rauch (of Sura Traction); Bengt Åkesson; Elisabet Lundqvist and Lennart Nordhall (both of Sura Traction); Mikael Fermér (of Chalmers Solid Mechanics); and Nils Månsson and Sven A Eriksson (both of SJ Machine Division)

Simulation of stop braking, drag braking and complete braking programs (sequences recorded in-field) is performed in an outdoor environment. Disc 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 fly-wheels, each at 630 kg and 267 kgm^2, with a maximum speed of 1500 rpm

Parameters controlled	**Results recorded**
Braking air pressure (max 5 bar)	Braking moment
Train speed (max 250 km/h)	Temperatures
Axle load (max 30 tonnes)	Strains and stresses
Environment (heat, cold, water, snow...)	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

SD5. ACTIVE AND SEMI-ACTIVE SYSTEMS IN RAILWAY VEHICLES

Aktiva och semiaktiva system i järnvägsfordon
Aktive und halbaktive Systeme in Eisenbahnfahrzeugen
Systèmes actifs et semiactifs dans les véhicules ferroviaires

Project leaders and supervisors	Professor Jonas Sjöberg, Signals and Systems, and Professor Thomas Abrahamsson, Applied Mechanics
Doctoral candidate	Mr Daniel Atieh, MSc (from 2001-11-01 to 2003-01-31)
	Ms Jessica Fagerlund, MSc (from 2003-03-24)
Period	2001-11-01 – 2006-06-30 (– 2007-06-30)
Chalmers budget (excluding university basic resources)	Stage 3: KSEK 1 175 Stage 4: KSEK 1 600 Stage 5: –
Industrial interests in-kind budget	Stage 3: KSEK 300 Stage 4: KSEK 200 *(Bombardier Transportation)* Stage 5: –

For a photo of Thomas Abrahamsson, see page 21

The dynamic variations in the track forces exerted on bogies and wagon bodies may be compensated for by use of sensors and actuators on board the running train. With feed forward control system procedures, it may be possible to utilize information on track properties provided by a preceding wagon in the train. Simulations and experiments will reveal to what extent the forces can be compensated for in a realistic situation. The main aim of the SD5 project is to develop a system that will improve comfort in passenger coaches.

A mathematical model of a railway car has been built using the MultiBody System (MBS) software SIMPACK. Track irregularities were imported to the model and simulations have been performed. The resulting car body accelerations and deflections have been studied as well as different ride indices. A number of control strategies have been tried. As an alternative to SIMPACK, the general computer program MATLAB has also been used in the modelling work.

It was found that an existing actuator prototype was strong enough to manage the quasi-static vertical forces needed to compensate for the variations of the loads on the vehicle. In the event the passive components are removed, the same actuator would not be strong enough to keep the car roll at the current level under all running conditions. However, the calculated difference was very small and it can be assumed that it will still be feasible to make the roll control active.

PhD student Jessica Fagerlund (right) and her supervisor Professor Jonas Sjöberg in project SD5

A simplified analytical model describing the motion of one bogie has been found insufficient for control design. Disturbances in the wheelsets of one bogie have a major influence on the behaviour above the other bogie, both vertically and in roll.

The reference group of project SD5 includes members from Banverket, Bombardier Transportation Sweden, Interfleet Technology and KTH Railway Group.

Jessica Fagerlund, Jonas Sjöberg and Thomas Abrahamsson: Passive railway car secondary suspension – force, power, deflections, roll and comfort, *Chalmers Signals and Systems,* Gothenburg 2005, 28 pp (availability restricted)

Jessica Fagerlund, Jonas Sjöberg and Thomas Abrahamsson: Briefly on passive railway car secondary suspension – force, power, deflection, roll and comfort, *Mechatronics Meeting,* Halmstad University (Sweden) November 2005, 3 pp

EU1. EUROSABOT

EuroSABOT — Sound attenuation by optimized 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 co-worker Hans Johansson, see page 58

EUROSABOT

EuroSABOT had a total budgeted project cost of KEUR 3 724 and a budgeted EU funding of KEUR 1 858. 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 brake blocks generating roughness (waviness, corrugation) on the wheel tread, which induces vibrations and noise. The aim of EuroSABOT and the EU1 project was to develop new and better brake blocks that cause less roughness on the wheel tread than cast iron blocks. CHARMEC's work was carried out in close collaboration with the VB2 project. A great deal of experimental work was done in the brake rig (inertia dynamometer) at Surahammar where Mr Hans Johansson assisted.

Professor Roger Lundén led the EU1 project. See also the CHARMEC Triennial Report from Stage 2.

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 des marchandises silencieux

For a photo of project leader Jens Nielsen, see page 24

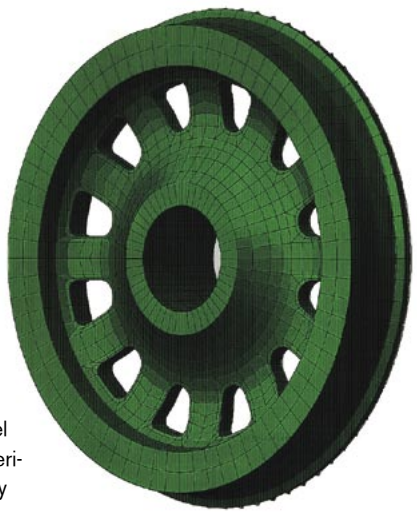
Silent Freight

Silent Freight had a total budgeted project cost of KEUR 3 196 and budgeted EU funding of KEUR 1 700. 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 a reduction in the noise level from the rolling stock used in freight traffic by 10 dB(A). CHARMEC's contribution was aimed at investigating whether a proposal put forward by us for a standard wheel with a perforated wheel disc could be a cost-effective solution and applicable on existing types of freight wagon wheels.

The sound radiation from prototypes of perforated wheels was calculated by means of the commercial SYSNOISE computer program and was measured in the test rig at Surahammar. The outcome of the EU2 project was that so-called acoustic short-circuiting (between the front and rear sides of the vibrating wheel disc) via suitable holes is an effective method in the frequency range up to ca 1 000 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 Jens Nielsen led the EU2 project. See also the CHARMEC Triennial Report from Stage 2.



Computer model of perforated wheel in project EU2. This 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 Infrastruktur
Développement de nouvelles technologies pour des infrastructures ferroviaires silencieuses

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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 the EU3 project was to reduce the noise level from tracks with freight traffic by 10 dB(A). CHARMEC's contribution was partly to further develop the DIFF model (see under project TS1) in order to study the origin of corrugation on the railhead and partly to propose a new sleeper with reduced radiated sound power. Simulation of corrugation growth in DIFF was calibrated and verified against measurements of wave formation on rails used on the 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 Jens Nielsen led the EU3 project. See also the CHARMEC Triennial Reports from Stages 2 and 3.

EU4. ICON

ICON – Integrated study of rolling contact fatigue
Integriertes Studium über Ermüdung durch Rollkontakt
Étude intégrée de la fatigue de contact au roulement

For a photo of project leader Lennart Josefson, see page 39

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 the EU4 project was to develop and verify a calculation model that could describe the initiation and early growth of cracks in the railhead. The activities within projects EU4 and MU6 were co-ordinated.

Professor Lennart Josefson led the EU4 project. See also the CHARMEC Triennial Report from Stage 2.

EU5. EUROBALT II

EUROBALT II – European research for an optimised ballasted track
Europäische Forschung für Optimierung von Gleisen auf Schotter
Recherche européenne pour l'optimisation des voies ferrées sur ballast

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For photos of project leaders Tore Dahlberg and Roger Lundén, see pages 58 and 63

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 reproduces and predicts 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 under project TS1. A resonance frequency between 20 and 30 Hz in the ballast/subgrade was included.

Professors Tore Dahlberg and Roger Lundén led the EU5 project. See also the CHARMEC Triennial Reports from Stages 2 and 3.

EU6. HIPERWHEEL

HIPERWHEEL — Development of an innovative, high-performance railway wheelset

Entwicklung eines innovativen leistungsstarken Radsatzes

Développement d'un essieu monté innovent à haute performance

Project leader	Professor Roger Lundén, Applied Mechanics
Co-workers	Docent Jens Nielsen, Applied Mechanics
	Dr Anders Ekberg, Assistant Professor, Applied Mechanics
Period	2000-04-01–2004-09-30
Budget EU	KEURO 141
Budget CHARMEC	Stage 3: KSEK 1 200 Stage 4: –

For photos of project leader and co-workers, see pages 24, 51 and 58

The HIPERWHEEL project of the Fifth Framework Programme comprised a total of 280 man-months and had a budgeted project cost of KEUR 3 690 and a budgeted EU funding of KEUR 1 979. Chalmers/CHARMEC's commitment to HIPERWHEEL was 13 man-months. Partners in the project were Centro Ricerche Fiat (Italy), Chalmers Solid Mechanics/CHARMEC (Sweden), Trenitalia (Italy), Fraunhofer-Institut für Betriebsfestigkeit LBF (Germany), Lucchini Sidermeccanica (Italy), Mechanical Dynamics Italy (Italy), Otto Fuchs Metallwerke (Germany), Politecnico di Milano (Italy), the Department of Mechanical Engineering at the University of Sheffield (UK), and Valdunes (France). The duration of the HIPERWHEEL project was 48+6 months and it 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 at attaining. Mechanisms of damage such as rolling contact fatigue of the wheel tread and fretting fatigue in the shrink-fit or press-fit between wheel and axle were considered. CHARMEC's main responsibility in the EU6 project was to study damage mechanisms in collaboration with the University of Sheffield and to act as task leader for "Numerical procedure for NVH analysis" (Work Package WP5).

CHARMEC also contributed with work in WP3 "Damage mechanisms acting on the wheelset and database for fatigue life prediction" and WP4 "CAE-based procedure for wheelset durability assessments". Several meetings were held with our partners in the project. Jens Nielsen attended the final meeting of HIPERWHEEL in Darmstadt (Germany) on 29 April 2005. One result of HIPERWHEEL is a new wheelset with 25% lower weight and where the disc is made of aluminium and the rim of high-strength steel. See also the CHARMEC Triennial Report from Stage 3.

Anders Ekberg: Predicting fretting fatigue of railway wheel-axle assemblies - a state-of-the-art survey, Research Report 2004:10, *Chalmers Applied Mechanics,* Gothenburg 2004, 38 pp

Anders Ekberg: Fretting fatigue of railway axles – review of predictive methods and outline of a finite element model, *IMechE Journal of Rail and Rapid Transit,* vol 218, no F4 (Special Issue on Railway Axles), 2004, pp 299-316 (this is a revised version of the above report)

Roger Lewis, Rob S Dwyer-Joyce, Stefano Bruni, Anders Ekberg, Mauro Cavalletti and Kamel Bel Knani: A new CAE procedure for railway wheel tribological design, *Proceedings 14th International Wheelset Congress,* Orlando FL (USA), October 2004, 14 pp (available on CD)

Jens Nielsen and Claes Fredö: Multi-disciplinary optimization of railway wheels, *Journal of Sound and Vibration,* vol 293, nos 3-5, 2006, pp 510-521. Also in *Proceedings 8th International Workshop on Railway Noise (IWRN8),* Buxton/Derbyshire (UK) September 2004, vol 1, pp 35-46

Project leader in project EU5 Professor Tore Dahlberg of Linköping Institute of Technology (formerly at Chalmers)

For the EU projects, it should be noted that the entry "budgeted project cost" includes the full costs borne by the industrial partners but excludes approximately half of the total costs borne by the University.

For the projects EU6 to EU10, these 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

Project leaders	Professor Lennart Josefson and Professor Roger Lundén, Applied Mechanics
Co-workers	Docent Jens Nielsen, Applied Mechanics
	Dr Jonas Ringsberg, Assistant Professor, Applied Mechanics
	Professor Birger Karlsson, Materials Science and Engineering
Period	2000-05-01–2003-10-31
Budget EU	KEURO 181
Budget CHARMEC	Stage 3: KSEK 2 100 Stage 4: –

For photos of the project leaders and co-workers, see pages 24, 37, 50 and 58

The INFRASTAR project of the Fifth Framework Programme comprised a total of 140 man-months with a budgeted project cost of KEUR 1 780 and budgeted EU funding of KEUR 1 080. Chalmers/CHARMEC's commitment to INFRASTAR was 20 man-months. Partners in the project were AEA Technology Rail (The Netherlands), Banverket (Sweden), Chalmers Applied Mechanics/CHARMEC (Sweden), Duroc Rail (Sweden), Inexa Profil (Sweden, up to October 2001), RATP (France), Corus (France), and the Department of Mechanical Engineering at the University of Sheffield (UK). The duration of the INFRASTAR project was 42 months and it 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. Two different technologies were meant to be studied: 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 during rail manufacture. One objective was to develop and validate a predictive model that could assist coating selection in the design of a fatigue-resistant two-material rail. During the course of the project, the latter of the two technologies was abandoned.

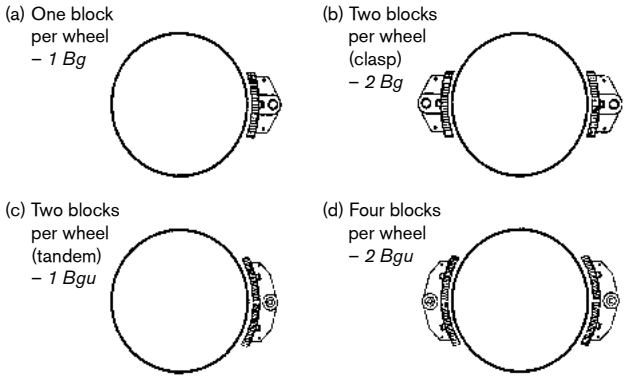
A systematic approach to the fatigue design of two-material rails under rolling contact load was devised and implemented. It incorporates dynamic train/track interaction simulations, three-dimensional finite element (FE) calculations, shakedown theory, and laboratory and field trials. Shakedown diagrams and calculations were used to illustrate how the improvement in shakedown performance of a coated rail varies with coating thickness, traction coefficient, contact load position, strength of coating and 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.

The tool for fatigue design has been validated against twin-disc experiments and can be used to quantify the influence of variations in load magnitude, contact patch size and rail profile. The influence of residual stresses, as generated during the production of a two-material rail, on the fatigue behaviour has also been quantified. See also the CHARMEC Triennial Report from Stage 3. Lennart Josefson, Jens Nielsen and Jonas Ringsberg participated in the final project management meeting on 18-19 December 2003 in Zeltweg (Austria).

Jonas Ringsberg, Francis Franklin, Lennart Josefson, Ajay Kapoor and Jens Nielsen: Fatigue evaluation of surface coated railway rails using shakedown theory, finite element calculations, and lab and field trials, *International Journal of Fatigue,* vol 27, no 6, 2005, pp 680-694

Jonas Ringsberg, Anders Skyttebol and Lennart Josefson: Investigation of the rolling contact fatigue resistance of laser cladded twin-disc specimens – FE simulation of laser cladding, grinding and a twin-disc test, *International Journal of Fatigue,* vol 27, no 6, 2005, pp 702-714 (also listed under project MU8)

Martin Hiensch, Per-Olof Larsson, Olof Nilsson, Didier Levy, Ajay Kapoor, Francis Franklin, Jens Nielsen, Jonas Ringsberg and Lennart Josefson: Two-material rail development – field test results regarding rolling contact fatigue and squeal noise behaviour, *Wear,* vol 258, nos 7-8, 2005, pp 964-972 (revised article from conference CM2003)



EU8. ERS

ERS — Euro Rolling Silently

Project leaders	Professor Roger Lundén, Applied Mechanics
Co-workers	Mr Martin Helgen, MSc, and Docent Jan Henrik Sällström, both of Epsilon HighTech
	Mr Tore Vernersson, Lic Eng, Applied Mechanics
Period	2002-09-01–2005-08-31
Budget EU	kEURO 206
Budget CHARMEC	Stage 3: kSEK 200 Stage 4: 1 000

For photos of project leader and co-workers, see pages 58 and 89

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 5 880 and budgeted EU funding of kEUR 2 470. Chalmers/CHARMEC's commitment to ERS was 20 man-months. Partners in the project were Chalmers Applied Mechanics/CHARMEC (Sweden), DB (Germany), SBB (Switzerland), SNCF (France) and Trenitalia (formerly part of FS, Italy) together with the six brake block manufacturers Becorit (Germany), Bremskerl Reibbelagwerke (Germany), Federal-Mogul Friction Products (formerly Ferodo, UK), Honeywell Bremsbelag (formerly Jurid, Germany), ICER (Spain), and CosRail (formerly RÜTGERS Rail). The duration of the ERS project was 36 months and it was co-ordinated by SNCF (Jacques Raison).

The aim of the ERS project was to develop new so-called "LL" type brake blocks for tread-braked freight wagons (there are presently around 650 000 in Europe). The blocks should be such that, without modification to the wagons, they can replace the existing cast iron blocks of grade P10 (i e, a retrofit solution is sought). The new blocks should (i) produce lower rolling noise than existing blocks (by causing only small irregularities on the tread of the wheels) and possibly (ii) result in lower life-cycle costs. Furthermore, they should (iii) have the same dimensions as today's cast iron blocks and (iv) behave in the same way as these in all operating situations (as regards block/wheel friction, wheel/rail adhesion, temperature distribution etc). In particular, the new brake blocks (v) should not absorb metal particles from the wheel. The blocks should (vi) be environmentally friendly and, finally, (vii) the remains of worn blocks should be recyclable. CHARMEC's investment in the ERS project consisted of a description of state-of-the-art and of thermomechanical simulations.

The thermomechanical capability of two freight wagon wheels (VMS from Valdunes and RAFIL from Radsatzfabrik Ilsenburg) has been evaluated. Temperature results from brake bench tests have been used for calibrating axisymmetric finite element models, including both wheel and brake block. The tests performed in the Lucchini/CHARMEC inertia dynamometer at Surahammar during March-April 2005 included investigation of the effect of rail chill (cooling of the rolling wheel through its contact with the rail, see project SD4). The results are included in the final technical report from Chalmers for the ERS Tasks 2.2 and 2.5, see below.

For a drag braking rig test with cast iron brake blocks in 2 Bgu configuration, it has been found that typically about 70% of the total braking power goes as heat into the wheel. With composition brake blocks in 2 Bg configuration, typically about 95% the total braking power goes as heat into the wheel. The effect of rail chill is important when calculating the wheel temperatures for a tread-braked system. Wheels in new, worn and fully worn conditions were analysed. Three standard load cases were used: Load Case 1 "St Gotthard" (gross braking power 45 kW per wheel, braking time 34 min), Load Case 2 "Wheel Validation" (50 kW, 45 min), and Load Case 3 "Fuse Test" (60 kW, 120 min). Load Case 2 is according to the standards EN 13979-1 and UIC 510-5. Load Case 3 is to find the wheel response when power corresponding to disintegration of the brake block is applied.

Tore Vernersson attended the ERS final meeting in Paris on 31 August 2005. Our final project reports, including TIP (Technological Implementation Plan) and financial reports, have been submitted, see below. See also the CHARMEC Triennial Report from Stage 3. The work in project EU8 has been co-ordinated with that in project SD4 "Control of block braking". See the SD4 project for further reports.

◄ Four common brake block arrangements. Two blocks can be used in either (b) clasp or (c) tandem arrangement. Bg and Bgu stand for "Bremsklotz geteilt" and "Bremsklotz geteilt unterteilt", respectively

Martin Helgen, Tore Vernersson, Roger Lundén and Jan Henrik Sällström: WP2 Thermomechanical modelling report, Euro Rolling Silently Report 2-PTR-CU-001, *Chalmers Applied Mechanics,* Gothenburg 2006, 72 pp + Appendices 106 pp (availability restricted)

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 – 2006-06-30 (– 2007-12-31)
Budget EU	Not specified
Budget CHARMEC	Stage 4: – Stage 5: kSEK 150

For photos of Roger Lundén and Anders Ekberg, see pages 51 and 58

EURNEX is a "European Rail Research Network of Excellence" under the Sixth Framework Programme. The aim of the network is to (i) integrate European rail research, (ii) promote railway contributions to a sustainable transport policy, (iii) improve competitiveness and economic stability of the railway sector, and (iv) achieve a self-standing and long-lasting business case for the network. The activities are oriented towards ERRAC's (European Rail Research Advisory Council) agenda, see www.eurnex.net.

The network is co-ordinated by FAV in Berlin (FAV stands for Forschungs- und Anwendungsverbund Verkehrssystemtechnik) and has close to seventy member organizations from 18 EU member states and Russia. Members from Sweden are Chalmers/CHARMEC, Linköping Institute of Technology, Luleå University of Technology, Uppsala University, and the Swedish National Road and Transport Research Institute (VTI).

Since the budget of a Network of Excellence is very small (a maximum of MEUR 6 in total), there is little room for common activities funded by the network. Instead, the network acts like the "Yellow Pages" or "Who's Who" for European research. It is also a platform for establishing ad hoc consortia of network members, e g, for developing research project proposals. The main part of the actual work within the network thus consists of identifying current and future competences and resources in railway research and education.

Anders Ekberg attended the kick-off meeting in Berlin (Germany) on 28-30 January 2004 , the second EURNEX Integration Conference in Berlin on 2-3 March 2005, and a first Nordic Network meeting in Stockholm on 21 October 2004. During 2005, all relevant CHARMEC research projects were registered in the EURNEX database. A EURNEX mini-symposium was held at Chalmers on 19 May 2005 with participants from Banverket, Bombardier Transportation, CHARMEC, Desolver, Interfleet Technology, KTH Railway Group, Linköping Institute of Technology and Manchester Metropolitan University (MMU). Anders Ekberg participated in the third EURNEX Integration Conference on 18 September 2006 in conjunction with the INNOTRANS fair in Berlin (Germany).

As EURNEX evolved, an organization according to ten "Poles of Excellence" was established. Anders Ekberg participated in a Pole 8 "Infrastructure and Signalling" workshop in Birmingham (UK) on 16 June 2005 and in a Pole 3 "Rolling Stock" meeting in Milan (Italy) on 31 August 2005. Anders Karlström took part in a Pole 7 "Environment and Energy Efficiency" workshop in London (UK) on 21 June 2005. Together with Karsten Lemmer of DLR Braunschweig (Germany), Anders Ekberg was appointed leader for Pole 8 from autumn 2005. In Pole 8, CHARMEC has submitted several sections to the position paper, see below, and we have participated in the drafting of a number of project proposals. These were used when EURNEX compiled an overall position paper for the EU Seventh Framework Programme.

EURNEX: Position paper on railway infrastructure and signalling, Version 1 dated 13 March 2006, *Chalmers Applied Mechanics,* Gothenburg 2006, 46 pp

Björn Paulsson, Martin Platzer and Anders Ekberg: INNOTRACK – Innovative Track System – a unique approach from infrastructure managers and competitive track supply industry to develop innovative products of the future, *Poster at 7th World Congress on Railway Research,* Montreal (Canada) June 2006, 12 pp

Roger Lundén and Peter Pointner: EU project INNOTRACK – Innovative Track Systems, Plenary Lecture at *7th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2006),* Brisbane (Australia) September 2006

EU10. INNOTRACK

INNOTRACK — Innovative Track Systems

Project leader	Professor Roger Lundén, Applied Mechanics/ Division of Dynamics
Co-workers	Docent Anders Ekberg, Docent Magnus Ekh, Dr Elena Kabo, Mr Elias Kassa, Lic Eng, Dr Göran Johansson, Professor Jens Nielsen and Mr Johan Sandström, MSc, all of Applied Mechanics, and Docent Jonas Ringsberg, Shipping and Marine Technology
Period	2006-09-01 –2009-08-31
Budget EU	KEUR 560
Budget CHARMEC	KSEK 2 850+1 200

For photos of project leader and co-workers, see pages 19, 24, 42, 43, 46, 51 and 58

Chalmers/CHARMEC is a partner in INNOTRACK. This is a new Integrated Project (IP) within the Sixth Framework Programme under the Priority 6 – Sustainable Development, Global Change and Ecosystems. It aims to deliver new products, processes and methodologies in order to achieve the ERRAC targets on increased quantities and qualities 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 aim. Common European practices for LCC and RAMS evaluations should be established. Subprojects (SP) of INNOTRACK are SP0 Project management (led by UIC with Banverket's Björn Paulsson as Project Manager), SP1 Duty/Requirements (led by Network Rail), SP2 Track support structure (led by SNCF), SP3 Switches and crossings (led by DB), SP4 Rails (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 4×300=1 200 included in Budget CHARMEC above).

INNOTRACK comprises a total of 1 266 man-months with a budgeted project cost of MEUR 18.6 (including budgeted EU funding of MEUR 10.0). The duration of the project is 36 months. Chalmers/CHARMEC's commitment is 40 man-months with EU funding of KEUR 560. The person responsible for the launching of INNOTRACK at the European Commission was William Bird.

Partners in INNOTRACK are AdIF (Spain), Alstom Transport SA (France), ARTTIC SA (France), Association of the European Railway Industries (UNIFE), Balfour Beatty Rail Projects Ltd (UK), Banverket (Sweden), Carillion Construction Ltd (UK), České dráhy as (Czech Republic), Chalmers/CHARMEC, ConTraffic GmbH (Germany), Corus (UK), Czech Technical University in Prague, Damill AB (Sweden), DB Netz AG (Germany), Delft University of Technology (The Netherlands), European Federation of Railway Track Work Contractors (EFRTC, Luxemburg), G-Impuls (Czech Republic), Goldsmidt Thermit GmbH (Germany), Laboratoire Central des Ponts et Chaussées (France), Manchester Metropolitan University (UK), Network Rail Infrastructure Ltd (UK), ÖBB–Infrastruktur Bau AG (Austria), ProRail BV (The Netherlands), RFF/ Réseau Ferré de France, RSSB (UK), SNCF (France), Speno International SA (Switzerland), TH Karlsruhe (Germany), UIC (Union Internationale des Chemins de fer, France), University of Birmingham (UK), University of Newcastle (UK), University of Southampton (UK), VAE GmbH (Austria), VAS/voestalpine Schienen GmbH (Austria), and Vossloh Cogifer SA (France).

Added financing (about KSEK 2 850) from Banverket and Chalmers will cover the difference between CHARMEC's full costs for INNOTRACK and the EU funding. The INNOTRACK Technical co-ordination group consisting of Björn Paulsson, Anders Ekberg and the SP leaders met in Paris on 30 August 2006. The next meeting of the group will be held at Chalmers on 13 December 2006. The formal INNOTRACK kick-off meeting was held in Berlin on 21 September 2006.

CHARMEC is involved in two subprojects. In SP3, low- and high-frequency simulations of train/switch interaction are being combined with local non-linear FE calculations to derive contact stress distributions and predict plastic deformation and cracking of rails and wheels. The overall aim is to optimize the switches in terms of LCC and RAMS for both the track structure and the passing vehicles.

In SP4, the overall aim is to establish a minimum action rule that can be applied to optimize maintenance intervals and, as much as possible, prevent operational interventions in the event of, e g, rail corrugation or rail cracks. CHARMEC is also involved in the work of defining more relevant tests for the classification of rail steels.

SP1. LUCCHINI SWEDEN AB (bilateral agreement)

Bilateral agreements have run since 1987, see page 83, 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 assist the Lucchini company on a continuous basis in the design, testing and marketing of wheelsets. Today, the contact persons are mainly 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).

SP2. NOISE FROM SWEDISH RAILWAYS

CHARMEC has been involved since 2002 in Banverket's overall efforts to bring down the noise emitted from Swedish railways. Results from the projects VB4, EU2 and EU3 have been exploited. See also under project SP10.

SP3. TRACK FORCE MEASUREMENTS ON X2

An extensive test campaign with field measurements of the track forces caused by the 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 Test Centre) with accelerometers and 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, say, 2000 Hz) where large contributions to peak loads may originate. CHARMEC contributed with background analysis and calculations.

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

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

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

SP6. DEVELOPMENT OF A QUIET RAIL

From September 2000, CHARMEC has had a development project aimed at the treatment and installation of rails with less noise radiation. Different shielding arrangements and absorbing materials have been tested. See the CHARMEC Triennial Report from Stage 3 and also project SP10.

SP7. LATERAL TRACK STABILITY

Lateral spårstabilitet

Project leader	Docent Anders Ekberg, Applied Mechanics/ Division of Material and Computational Mechanics
Co-workers	Dr Elena Kabo, Applied Mechanics, and Dr Erland Johnson, Mr Lars Jacobsson, Lic Eng, Dr Gunnar Kjell and Mr Robert Lillbacka, Lic Eng, all four of SP Swedish National Testing and Research Institute
Period	2003-01-01 – 2006-06-30 (–2006-12-31)
Chalmers budget (excluding university basic resources)	Stage 3: KSEK 300+335 Stage 4: KSEK 365+2500

One of the most feared phenomena in railway operations is the formation of sun-kinks on the track, 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 current project aims to prevent the occurrence of sun-kinks. Two pieces of vital information needed are (i) the magnitude of the compressive axial forces in the rails and (ii) the resistance of the track to lateral displacement and buckling.

The total axial forces comprise "live forces" from running (and braking) trains which can be estimated from measurements and simulations. More cumbersome are the "dead forces" owing to, e g, temperature, tamping and rail creep. The temperature forces are zero at a certain "neutral temperature". Knowledge of this temperature is important since it governs which higher temperature the track can sustain before sun-kinks are likely to occur. To find the neutral temperature using today's field measurements requires operations which are costly in terms of both labour and traffic disturbance. One aim of the SP7 project is to investigate, and possibly develop, better methods for measurement of the neutral temperature.

The other focus of the project is on track stability with its dependence on the lateral stiffness of rails, fastenings and ballast. Stability analyses are notoriously difficult and this is even more so in the lateral direction of the current track system, where both the mechanical properties of the components and their interaction are poorly understood. Through numerical simulations, an improved understanding should be obtained and a predictive model for the occurrence of sun-kinks be established.

Finite element (FE) simulations in 2D and 3D have been performed to establish the lateral force-deflection characteristics (up to 20 mm) of a sleeper embedded in ballast. Parameters such as load magnitudes (in three directions), sleeper/ballast friction and ballast geometry are varied. A constitutive model for ballast resistance has been developed and implemented in a user-defined element for the finite element program ABAQUS to simulate the coupling between sleepers and ground. The model has been calibrated using published results from experiments carried out at Delft University of Technology in The Netherlands.

A literature overview has been made of different techniques for measurement of the axial forces in rails, such as the traditional rail uplift method and the ultrasonic, strain-gauge and magnetic methods which register local stresses. A number of methods for the dynamic measure-

Photo: Frida Hedberg, Aftonbladet Bild

Derailment of the last two coaches in a 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 eye-witnesses, the lateral buckling and displacement of the track gradually grew as the train braked

SP7. (cont'd)

Experimental set-up at the SP laboratory in project SP7. From the left: Docent Anders Ekberg and Dr Elena Kabo of Chalmers Applied Mechanics together with Dr Gunnar Kjell, Dr Erland Johnson, Mr Robert Lillbacka, Lic Eng, and Mr Lars Jacobsson, Lic Eng, of SP Swedish National Testing and Research Institute (from 2007-01-01: SP Technical Research Institute of Sweden)

ment of the axial rail forces have also been identified. Among the most promising of these were (1) transverse horizontal excitation of the rail with an electromagnetic shaker and measurement of the wavelength of the response in the rail and (2) transverse horizontal excitation of the whole track system, including rails, sleepers and ballast, and interpretation of the frequency response in terms of a total risk for sun-kinks due to a combination of high axial rail forces and low lateral track stiffness.

The wavelength method (1) requires both measurements and FE calculations with very high accuracy. To evaluate the method, a 12-metre-long UIC60 rail on pads and 18 sleepers has been installed in the SP laboratory in Borås (Sweden). An axial load of up to 500 kN can be applied. The rail has been laterally excited and its deflection measured at various axial load levels. The corresponding changes in wavelengths, due to the axial load, have been estimated from the FE calculations. The other way around, the axial load levels were then estimated from the measured wavelengths. The results show a high sensitivity to some input parameters. These have been identified and further calibration will be needed before the method is operational.

As regards the resonance method (2), lateral accelerations of a rail due to the passage of different types of trains have been evaluated from field measurements and the lowest lateral resonance frequency has been estimated. An FE model of a track has been employed to calculate resonance frequencies corresponding to different axial forces and for varying track characteristics. Field measurements and model calculations show similar results for the lowest resonance frequency and the simulations have quantified the influence on this lowest resonance frequency of the lateral stiffness of the track and of the axial force. The latter influence was found to be comparatively weak, which is a clear drawback.

Elena Kabo, Anders Ekberg and Lars Jacobsson: Railway track stability – a state-of-the-art survey, Research Report 2004:2, *Chalmers Applied Mechanics,* Gothenburg 2004, 94 pp

Erland Johnson: Measurement of forces and neutral temperatures in railway rails – an introductory study, Report 2004:11, Building Technology and Mechanics, *SP Swedish National Testing and Research Institute,* Borås 2004, 69 pp

Elena Kabo, Anders Ekberg and Lars Jacobsson: Spårstabilitet – en introduktion för bantekniker (Track stability – an introduction for track technicians; in Swedish), Research Report 2004:3, *Chalmers Applied Mechanics,* Gothenburg 2004, 20 pp

Erland Johnson: Vibrational methods for measuring axial rail force, SP Technical Note 2005:11, Building Technology and Mechanics, *SP Swedish National Testing and Research Institute,* Borås 2005, 47 pp

Lars Jacobsson: A plasticity model for ballast resistance, SP Report 2005:27, *ibidem,* 35 pp

Lars Jacobsson: User element for ABAQUS designed to represent ballast resistance, SP Technical Note 2005:12, *ibidem,* 12 pp

Erland Johnson: The mathematics behind a guided wave technique for rail force determination, SP Technical Note 2005:10, *ibidem,* 24 pp

Elena Kabo: Ballastgeometrins inverkan på spårets sidomotstånd – en parameterstudie (Influence of ballast geometry on the lateral resistance of the track – a parametric study; in Swedish), Research Report 2005:09, *Chalmers Applied Mechanics,* Gothenburg 2005, 29 pp

Henrik Snygg: Resonansstudie av spårsystem – räl, pads, slipers och ballast (Resonance study of track systems – rails, pads, sleepers and ballast; in Swedish), SP Technical Note 2006:10, Building Technology and Mechanics, *SP Swedish National Testing and Research Institute,* Borås 2006, 34 pp

Elena Kabo: A numerical study of the lateral ballast resistance in railway tracks, *IMechE Journal of Rail and Rapid Transit,* vol 220, no 4, 2006, pp 425-433

SP8. DESIGN OF INSULATED JOINTS

Utformning av isolerskarvar

Project leader	Dr Elena Kabo, Applied Mechanics/ Division of Material and Computational Mechanics
Co-workers	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 42

Work in this project has been moved to TS8, see under that project.

Jens Nielsen: Modellering av isolerskarv i DIFF (Modelling of an insulated joint in DIFF; in Swedish), Research Report 2004:13, *Chalmers Applied Mechanics,* Gothenburg 2004, 7 pp

Elena Kabo: Förstudie av isolerskarvars inverkan på spårets mekaniska egenskaper – en finit element-analys (Prestudy of the influence of an insulated joint on the mechanical properties of the track – a finite element analysis; in Swedish), Research Report 2004:14, *Chalmers Applied Mechanics,* Gothenburg 2004, 12 pp

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* (in press. Also listed under projects TS8 and MU9)

Damaged insulating joint at Järna south of Stockholm. Running direction of train is from right to left. 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

SP9. SLEEPER DESIGN FOR 30 TONNE AXLE LOAD

Sliperutformning för 30 tons axellast

Project leader	Professor Jens Nielsen, Applied Mechanics
Co-workers	Dr Rikard Bolmsvik, Abetong Teknik
Period	2004-07-01 – 2005-06-30
Chalmers budget (excluding university basic resources)	Stage 4: –

For photos of Jens Nielsen and Rikard Bolmsvik, see pages 24 and 75

The design of new concrete sleepers for the Iron Ore Line (Malmbanan) in Northern Sweden has been studied at the request of Banverket with regard to the increase in the maximum axle load from 25 to 30 tonnes. It should be noted that Rikard Bolmsvik took his PhD within the framework of project MU5, see CHARMEC's Triennial Reports from Stages 2 and 3. The study was financed by Banverket.

The sleeper loading at different train speeds on the existing track has been simulated using the in-house program DIFF, see project TS1. A dynamic design model was compared with the traditional static model. The influence of impacts from wheel flats of varying size has been studied in particular.

Rikard Bolmsvik and Jens Nielsen: Sleeper for 30 tonne axle load, part I – initial study, *Abetong Teknik AB,* Växjö (Sweden) August 2004, 10 pp

Rikard Bolmsvik and Jens Nielsen: Sleeper for 30 tonne axle load, part II – extended studies, *Abetong Teknik AB,* Växjö (Sweden) May 2005, 17 pp

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 (BBS), Mr Jan Spännar, Lic Eng (BBS), Dr Martin Li (BBS) and Ms Karin Blidberg (SM) all four of Banverket
Period	2005-01-01 – 2006-06-30 (–2008-12-31)
Chalmers budget (excluding university basic resources)	Stage 4: kSEK 300+300+200 Stage 5: kSEK 600

For a photo of Jens Nielsen, see page 24

To meet noise legislation and to support long-term political, environmental and logistical objectives, greater understanding is needed of the railway noise emission and propagation and of the nuisance it may bring to people living near railway lines. The most efficient means of controlling noise is to attenuate its generation at the source in the wheel/rail contact. This can be achieved by regular rail grinding and wheel turning to reduce wheel/rail surface irregularities, by replacing cast iron brake blocks with blocks made of other materials, and by using track vibration absorbers. Several research projects focusing on railway noise are currently being run at Banverket. These projects include (i) developing technology for frequent and regular measurement of short-wavelength rail irregularities using Banverket's so-called STRIX car, (ii) surveying the noise reduction measures market, (iii) introducing track vibration absorbers at hot spots in the railway network, (iv) developing a database of models of tracks and vehicles representative of Swedish conditions to be used with the noise prediction software TWINS, (v) participating in the EU integrated project QCITY (Quiet City Transport comprising a total of 1041 man-months and with budgeted EU funding of MEUR 7.40), 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 the noise projects within the Green Train Programme in Sweden, see page 87. The aim of SP10 is to integrate these projects to increase efficiency and achieve synergy effects. This task has been assigned to CHARMEC's Jens Nielsen.

A project steering group with Banverket's Magnus Bengtsson (CFP), Tohmmy Bustad (CBF), Sören Dahlén (CSM), Bertil Eriksson (CBBS) and Björn Paulsson (CBB) has been formed. Banverket is a partner in QCITY with a commitment of 6 man-months plus in-kind contributions.

Banverket's employees (from left) Nicolas Renard, Karin Blidberg and Simon Gripner (the latter substituting for Jan Spännar). Photo taken outside the Borlänge office in November 2006

Two official test sites in Sweden for the assessment of noise reduction measures have been selected, one at Tjörnarp in southern Sweden between Höör and Hässleholm (UIC60 rail) and one at Partille outside Gothenburg (BV50 rail). At Tjörnarp there have been measurements of track receptance, track decay rate, rail roughness (by Banverket PMM) and pass-by noise (by Acoustic Control AB). This was done in order to define a QCITY reference system for freight traffic to be used for comparison of different noise reduction measures. Jens Nielsen participated in the kick-off meeting for the EU project QCITY on 24-25 February 2005 in Leuven, Belgium.

Based on STRIX measurements on several tracks, a transfer function to assess short-wavelength vertical rail irregularities from measured axle box accelerations has been derived. The agreement between rail roughness levels measured by STRIX and those measured by the Corrugation Analysis Trolley (CAT) is good for continuously welded rails. A benefit of the STRIX system is that the Swedish railway network can be measured and assessed

SP10. (cont'd)

on a regular and frequent basis. Results from the STRIX system are presented as rail roughness levels relative to the ISO 3095 limit roughness level (corresponding to a good track) evaluated in one-third octave bands and versus track position. This means that sections of track with poor rail quality (corrugation) can be identified.

A tuned rail vibration absorber from Corus Rail UK has been installed in the reference track at Tjörnarp. Sound pressure levels at 7.5 m from track centre were measured at three track sections: one reference section without dampers, one section with the Corus damper, and one section with a Finnish damper called Teknikum. A TWINS database containing models of tracks and vehicles representative of Swedish conditions has been delivered to Banverket. 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. A report defining and describing the reference track at Tjörnarp, including a comparison of measured and calculated pass-by noise levels, has been delivered to the QCITY consortium. Good agreement between measured and calculated sound pressure levels (SPL) at 7.5 m from track centre was obtained with respect to both the total level and the shape of the spectrum. The analysis showed that rail noise dominates the total noise in the frequency interval 300-2 000 Hz. Preliminary results from the measurements at Tjörnarp indicated a 3 dB reduction in SPL at 7.5 m from track centre for most train types when the Corus tuned rail damper is used. The less expensive Teknikum damper resulted in a 2-3 dB reduction. Further field tests with noise-reducing measures will be performed on the reference track at Tjörnarp when other types of rail dampers have been identified and installed. An assessment of the influence of combined wheel and rail damping on noise levels will be performed.

Nicolas Renard, Jens Nielsen, Henrik Malker and Henrik Samuelsson: Definition of a reference system for freight trains to compare against in quantification analyses – the Tjörnarp site for railway noise studies, Technical Report QCITY, *EU Sixth Framework Programme,* Contract no TIP4-CT-2005-516420, 19 pp and 10 appendices

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 – 2006-06-30 (–2007-12-31)
Chalmers budget (excluding university basic resources)	Stage 4: KSEK 365 Stage 5: KSEK 435

During 2000 and 2002, vertical contact force measurements were carried out using an instrumented X2 trainset, see project SP3. Analysis of part of the measured data revealed that extreme loads have a large high-frequency content. Numerical simulations have indicated that these extreme loads are of vital importance in the degradation of tracks and wheels. The overall aim of project SP11 is to (i) clarify the occurrence of high-frequency vertical wheel/rail contact forces at high-speed operations on Swedish railways, and (ii) further the understanding, prediction and counteracting of cracks in wheels and rails as a consequence of rail and wheel corrugation. Ultimately, such knowledge should lead to safer and more economic train operations and to an optimization of maintenance activities.

Project SP11 contains the following tasks: (1) refining of a computer-based tool to analyze measured data, (2) state-of-the-art survey of methods for measuring rail corrugation, (3) improvement of filters for force data analysis, (4) DIFF modelling of wheel/rail interaction, (5) FIERCE analysis of rolling contact fatigue, (6) development of analysis tools for the handling of large data files, (7) analysis of rail corrugation data, (8) development of

SP11. (cont'd)

acceptance criteria for rail irregularities, (9) evaluation of rail irregularities in relation to Banverket's database BIS, and (10) writing of reports. CHARMEC is involved in tasks 2, 4, 5, 8 and 10.

The project is conducted through co-operation between Interfleet Technology and CHARMEC. Funding to Interfleet Technology has been granted by Banverket. An agreement on the project between CHARMEC and Interfleet Technology was signed in May 2005. The project is part of the Green Train Programme in Sweden (see page 87), which aims to develop a new train generation for a speed of 250 km/h.

A state-of-the-art study on measurements of rail irregularities and on high-frequency train/track dynamics has been performed by Dr Anders Johansson. Rail roughness measured by Banverket using the Corrugation Analysis Trolley (CAT) on ten track sections between Stockholm and Gothenburg has been used as input for a simulation model in DIFF with the aim of comparing frequency spectra from measured and calculated contact forces for given track sections and to determine the frequency intervals where each method seems reliable. A filter which suppresses disturbing resonances of the instrumented wheelsets has been developed and implemented in the signal processing for obtaining the wheel/rail contact forces. The results from the field measurements in October 2002 have been processed. In parallel, DIFF calculations have been performed. Four train models and two viscoelastic track models were compared. The track models were calibrated against test data from laboratory and field tests. The contribution of high-frequency dynamics to wheel/rail contact forces has been analyzed and quantified.

A meeting of the reference group for project SP11 at the office of Interfleet Technology in Solna (Sweden) on 18 October 2006. From the left: Per Gullers (Interfleet), Johan Oscarsson (Interfleet), Roger Lundén (CHARMEC), Tohmmy Bustad (Banverket), Lennart Warsén (SJ), Lars Andersson (Interfleet), Jens Nielsen (CHARMEC) and Simon Gripner (Banverket).

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

Good correlation between measured and simulated contact forces was obtained in a wide frequency range. High-frequency dynamics in the range 100-1 250 Hz was found to contribute significantly to contact forces which are important in the development of rolling contact fatigue. A reference rail roughness spectrum based on observed severely corrugated stretches of track is being analyzed with DIFF. A parametric study with different levels of corrugation (reference level ±3 dB etc) and different train speeds (150-275 km/h) and rail pad stiffnesses is being performed to find their influence on contact forces and rolling contact fatigue.

The reference group of project SP11 includes members from Banverket, CHARMEC, Interfleet Technology and SJ AB.

Anders Johansson: Rail roughness measurements, rail grinding strategies and numerical simulations of rail roughness growth – a literature survey, Research Report 2006:03, *Chalmers Applied Mechanics,* Gothenburg 2006, 20 pp

Jens Nielsen: High-frequency vertical wheel–rail contact forces – validation of a prediction model by field testing, *Proceedings 7th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2006),* Brisbane (Australia) September 2006, vol 1, pp 41-48 (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, *ibidem,* vol 1, pp 137-143

Jens Nielsen, Anders Ekberg and Roger Lundén: Influence of short-pitch wheel/rail corrugation on rolling contact fatigue, *IMechE Journal of Rail and Rapid Transit,* vol 219, no F3, 2005, pp 177-187 (also listed under projects TS8 and MU9). In July 2006 this paper obtained the *IMechE Railway Division W A Agnew / C N Goodall Award 2005*

SP12. NEW SLEEPER SPECIFICATIONS

Nya sliperspecifikationer

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

For a photo of Jens Nielsen, see page 24

The project was initiated by Banverket and is based on previous work in project SP9. The general issue of how to specify the dimensioning loading on, and the structural model of, a concrete sleeper is approached. The design of sleepers for a 35 tonne axle load is of special interest.

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 existing sleepers were originally designed for an axle load of 22.5 tonnes and some cracking on the upper surface at the centre section of these sleepers has been observed. The influence of wheel tread defects (wheel flats) and of a non-uniform distribution of support stiffness along the sleeper is being studied. The bending moments in the sleepers at the rail seat and centre sections have been calculated using CHARMEC's simulation model DIFF, see project TS1, for dynamic interaction between train and track. Based on in-situ strain gauge measurements, actual sleeper bending moments at Harrträsk, see project TS9, have been determined and used to validate the model. Sleepers with a cracked and non-cracked centre section have been studied and the risk of fatigue failure has been evaluated using statistics gathered at the wheel damage detector at Harrträsk.

The outcome of project SP12 should be a new technical standard which can be used as a basis when new sleepers are to be purchased by Banverket. The preliminarily proposed dimensioning bending moments for an axle load of 35 tonnes and a maximum speed of 80 km/h are 22 kNm at the rail seats and –14 kNm at the centre of the sleeper.

Rikard Bolmsvik and Jens Nielsen: Dimensionerade böjmoment i sliprar vid 35 tons axellast (Dimensioning bending moments in sleepers for an axle load of 35 tonnes; in Swedish), Research Report 2006:9, *Chalmers Applied Mechanics,* Gothenburg 2006, 44 pp

Dr Rikard Bolmsvik at Abetong Teknik's sleeper testing machine in the factory at Vislanda (Sweden)

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 Dr Elena Kabo, Applied Mechanics
Period	2006-10-01 – 2007-06-30
Chalmers budget (excluding university basic resources)	Stage 5: KSEK 300

For photos of Jens Nielsen, Anders Ekberg and Elena Kabo, see pages 24 and 42

The current criterion in Sweden for removal of wheels with a flat is based on the length of the flat, which may not exceed 40 mm or 60 mm. In the latter case, immediate action is required. As a more rational alternative, project SP13 will focus on the maximum contact force that a damaged wheel exerts on the rail. In today's wayside detectors, the lowest alarm limit has been put at 290 kN.

New preliminary alarm limits will consider the risk of rail fracture caused by a damaged wheel. The study will include rail defects, residual stresses at welds and deviations from the neutral temperature of the rail. Simulations with DIFF, see project TS1, together with Banverket's measurements will be used. In a first phase only cracking because of defects in the rail head (and not in the rail web or rail foot) will be investigated.

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 December 2006).

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

Doctor of Engineering (PhD)

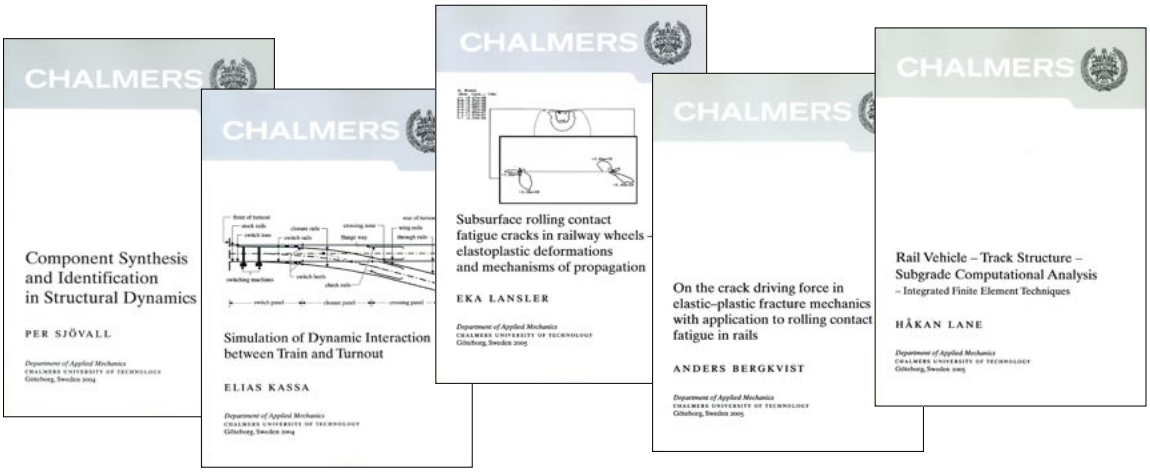
Jens Nielsen	1993-12-16
Mikael Fermér	1993-12-17
Annika Igeland	1997-01-24
Åsa Fenander	1997-05-23
Johan Jergéus	1998-01-30
Anders Ekberg	2000-04-07
Johan Jonsson	2000-06-09
Jonas Ringsberg	2000-09-15
Johan Ahlström	2001-03-02
Johan Oscarsson	2001-04-20
Rikard Gustavson	2002-11-07
Torbjörn Ekevid	2002-12-18
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

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

Adjunct Professor

Jens Nielsen	2006-07-01



Licentiate theses and doctoral dissertations submitted by CHARMEC researchers during Stage 4.

Note that another two theses and four dissertations were submitted during autumn 2006

INTERNATIONAL CONFERENCES

During Stage 4 (and the months immediately following Stage 4) researchers from CHARMEC have participated in, and contributed to, the following major seminars, workshops, symposia, conferences and congresses:

The 6th Internationale Schienenfahrzeugtagung (RAD Schiene 2003) in Dresden (Germany) 8-10 October 2003

The 10th IEEE Pacific Rim International Symposium on Dependable Computing (PRDC2004) in Papeete (Tahiti) 3-5 March 2004

The 4th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS2004) in Jyväskylä (Finland) 24-28 July 2004

The 22nd International System Safety Conference (ISSC22) in Providence RI (USA) 2-6 August 2004

The 8th International Workshop on Railway Noise (IWRN8) in Buxton/Derbyshire (UK) 8-11 September 2004

The ISMA (International Software Measurement & Analysis) 2004 Conference on Noise & Vibration Engineering in Leuven (Belgium) 20-22 September 2004

The 17th Nordic Seminar on Computational Mechanics (NSCM-17) in Stockholm (Sweden) 15-16 October 2004

The 14th International Wheelset Congress (IWC14) in Orlando FL (USA) 17-21 October 2004

The 11th International Conference on Fracture (ICF11) in Turin (Italy) 20-25 March 2005

The 8th International Heavy Haul Conference (IHHC2005) in Rio de Janeiro (Brazil) 16-18 June 2005

The 8th US National Congress on Computational Mechanics (USNCCM8) in Austin TX (USA) 24-28 July 2005

The International Conference on Mathematical Modelling of Wave Phenomena (MMWP2005) in Växjö (Sweden) 14-19 August 2005

The 19th IAVSD (International Association for Vehicle System Dynamics) Symposium, Dynamics of Vehicles on Roads and Tracks, in Milan (Italy) 29 August – 2 September 2005

The 8th International Conference on Computational Plasticity (COMPLAS2005 / An ECCOMAS Thematic Conference) in Barcelona (Spain) 5-8 September 2005 (here ECCOMAS stands for European Community on Computational Methods in Applied Sciences)

The 2nd International Conference on Adaptive Modeling and Simulation (ADMOS2005 / An ECCOMAS Thematic Conference) in Barcelona (Spain) 8-10 September 2005

The 2nd International Symposium on Environmental Vibrations – Prediction, Monitoring, Mitigation and Evaluation in Okayama (Japan) 20-22 September 2005

The 24th International Modal Analysis Conference (IMAC XXIV) in St Louis MO (USA) 30 January – 2 February 2006

The 14th IFAC (International Federation of Automatic Control) Symposium on System Identification (SYSID2006) in Newcastle (Australia) 29-31 March 2006

The 9th International Fatigue Congress (IFC9) in Atlanta GA (USA) 14-19 May 2006

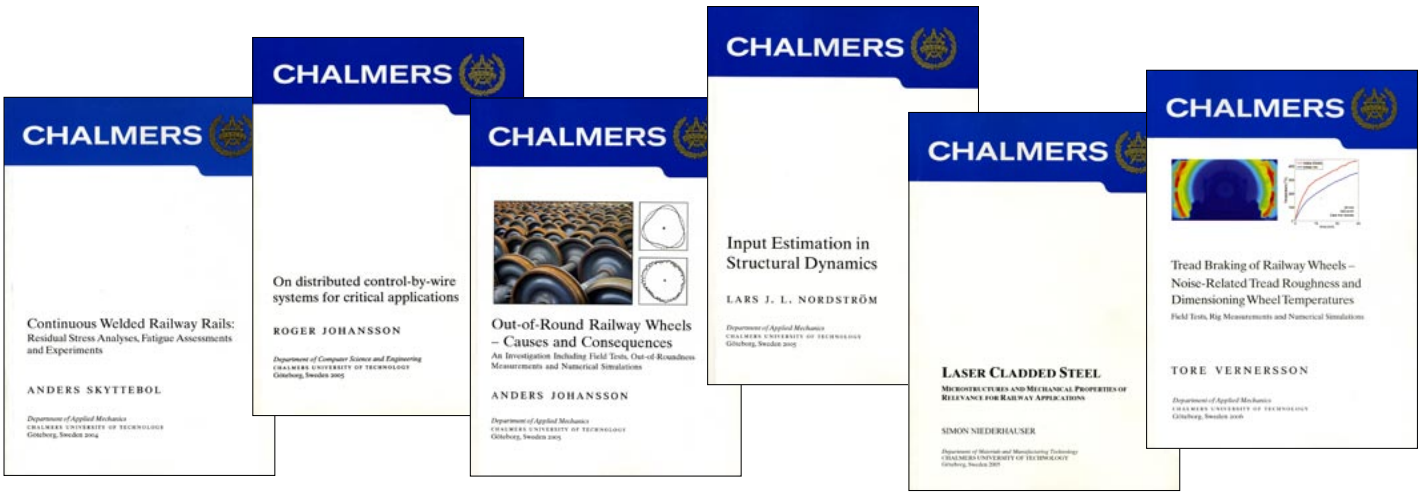
The 7th World Congress on Railway Research (WCRR2006) in Montreal (Canada) 4-8 June 2006

The 3rd European Conference on Computational Mechanics (ECCM2006) in Lisbon (Portugal) 5-9 June 2006

The 16th European Conference of Fracture (ECF16) in Alexandroupolis (Greece) 3-7 July 2006 (under ESIS, the European Structural Integrity Society)

The 12th International Conference on Computational and Applied Mathematics (ICCAM2006) in Leuven (Belgium) 10-14 July 2006

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



PARTNERS IN INDUSTRY

The status reported below by the partners is as of November-December 2006. The new partners for Stage 5, SJ AB and SweMaint AB, have also been included. For each partner the first year of 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 Teknik AB and its parent company Abetong belong to the HeidelbergCement Group and are manufacturers of pre-fabricated and pre-tensioned concrete structural components. About 600 people are employed in subsidiaries and associate companies in Sweden and abroad. Areas of interest for Abetong Teknik AB, with is headquarters in Växjö, are the design and manufacturing of railway sleepers fitted with fastenings and pads for rails. Tools useful in practice for the identification of loads on sleepers installed in tracks and for the structural analysis and design of sleepers for main lines and turnouts are of particular interest, as is the volume of noise emitted by the sleepers. The main purchasers of sleepers are state railways and railway contractors. A total of around three million Abetong sleepers are produced annually at wholly and partly owned and licensed sleeper plants at some 25 locations around the world.

Banverket (1995 and 1990)

Banverket, abbreviated BV, is the country's infrastructure authority and manager with a total of 8 000 employees. CHARMEC's partner is the headquarters in Borlänge with 600 employees although some regional offices are also involved. 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. It is particularly important to understand and predict the effect on the track of proposed higher train speeds and increased axle loads. Of primary importance also is research into vibration, noise and safety. In Sweden, Banverket has overall responsibility for the railway sector (both infrastructure and rolling stock and including underground systems and tramways).

Bombardier Transportation Sweden AB (2000)

Bombardier Transportation is a global manufacturer of equipment for railway operations and a provider of maintenance and service of rolling stock. The range of products includes passenger coaches, total transit systems, locomotives, freight cars, propulsion systems and rail control solutions. The total number of employees is 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 areas of interest in CHARMEC are focused on wheel/rail interaction and its effects on ride dynamics, wheel wear, wheel damage, and rolling noise. Also of interest are the transmission into the bogie and car body of wheel/rail-generated vibrations, the identification of contact forces and the application of active control systems for enhanced comfort. Finally, the company is interested in an improved 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.

Duroc Rail AB (1997 to 2006)

This is a company within the Duroc Group with a large share of the Swedish railway wheelset maintenance market in which it carries out traditional turning of wheels etc. The company's development work has focused on coating techniques for the running surfaces of wheels and rails. Different metallic, ceramic and composite materials are deposited in thin layers on these surfaces to modify their friction coefficient, decrease the wear and protect against rolling contact fatigue. Duroc Rail is located in Luleå with 25 employees. Areas of interest in the co-operation with CHARMEC have been general issues relating to wheel/rail contact and in particular to the surface properties, binding conditions and life spans of laser-treated wheel treads and rail heads.

Faiveley Transport Malmö AB (1997)

Faiveley Transport is one of the largest railway equipment suppliers in the world with its headquarters in Paris and with production units in Sweden, Germany, France, Italy, the UK and several other countries. The total number of employees is 3 500, of whom 110 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 being sought.

Green Cargo AB (2000)

This is a state-owned Swedish logistics company with its headquarters in Stockholm/Solna and with 3 200 employees at over 100 locations throughout the Nordic region and Europe. Green Cargo operates 435 locomotives and 7 000 freight wagons and covers approximately 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 as far as possible and the rail operations are complemented with road freight to the final destination. Services include warehousing as well as advanced logistics solutions. Areas of interest in the co-operation with CHARMEC are braking and noise emission and also 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 over 450 employees on three continents. Its clients are governments, administrations and companies, including manufacturers, contractors and operators as well as banks, investors and development agencies. The Swedish company Interfleet Technology AB is headquartered in Stockholm/Solna and has around 100 employees.

Lucchini Sweden AB (1995 and 1987)

This is a railway wheelset manufacturer in Surahammar with 50 employees. The company is a wholly owned subsidiary of the Lucchini Group in Italy (worldwide, Lucchini has approximately 8 000 employees in 10 countries). Areas of interest for Lucchini Sweden are the design, manufacturing, mounting, running, braking and maintenance of wheelsets. Of particular interest are new materials for wheelsets and noise emission from wheels. The main purchasers of the wheelsets are the passenger train operator SJ, the freight train operator Green Cargo and Bombardier Transportation Sweden, although the export of products and services to customers outside Sweden is becoming increasingly important.

SJ AB (2006)

SJ is a state-owned company headquartered in Stockholm. Its main activity is the operation of inter-regional and long-distance rail services in Sweden, and its main customer groups are private and business travellers and commuters. New double-decker trains and newly refurbished X2 trains entered service during the first quarter of 2005. A high standard of traffic safety is a fundamental component of SJ's vision. The SJ Group has some 3 100 employees, of which the Rail Traffic division employs 2 100 on-train staff and train drivers. Investments at Group level during 2005 totalled MSEK 1 400, consisting chiefly of modernization work on X2 trains and the purchase of new double-decker trains. SJ expects that the CHARMEC research projects will provide an increased understanding and thereby a better platform for improving technical solutions and maintenance work for its rolling stock.

AB Storstockholms Lokaltrafik (2003)

SL (Storstockholms Lokaltrafik) is the Stockholm Urban Transit Authority. SL administers the operation, maintenance and renewal of all fixed railway installations, rolling stock and real estate within the Greater Stockholm Area railway network. This network consists of three underground lines, three local railways and two tram lines with a total track length of 450 km. SL also operates two commuter lines on Banverket tracks as well as all bus traffic in the area. These systems cater for some 2.3 million passenger trips every day, of which 1.3 million are on track and 1.0 million on roads (buses). CHARMEC's partner is the headquarters in Stockholm, mainly the track and rolling stock departments. Areas of principal interest are vibrations and noise, track and vehicle maintenance, and materials. Of particular interest are the wear and dynamics of switches (turnouts) and also 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 customers a complete and cost-effective range of maintenance services, technical support and supply of 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 250 employees. The headquarters and the main workshop with modern wheelset maintenance facilities are located in Gothenburg. The annual turnover is MSEK 400 and the market share in Sweden is approximately 65%. One of SweMaint's main business areas is the management and operation of a wheelset pool for freight wagons. More than 10 000 wagons with over 30 000 wheelsets are connected to the pool. Areas of interest in the co-operation with CHARMEC are related to improved wheelset quality from a general point of view.

PARTNERS IN INDUSTRY (cont'd)

voestalpine Bahnsysteme GmbH & CoKG (2003 and 2002)

The Austrian company voestalpine Bahnsysteme GmbH & CoKG is one of four divisions of voestalpine AG and has about 7000 employees worldwide. For the financial year 1 April 2005 – 31 March 2006, the sales of the voestalpine Group (including all four divisions) amounted to about MEUR 5800. voestalpine Bahnsysteme GmbH & CoKG produces the world's broadest assortment of high-quality rails and switches (turnout systems), wire rod and drawn wire, seamless tubes as well as semi-finished steel products. Furthermore, the division offers a complete service for railway construction, including planning, transport, logistics and laying. It also produces its own steel.

The company voestalpine Schienen GmbH runs Europe's most modern and largest rail rolling mill in Leoben/Donawitz, Austria. All rails can be produced in supply lengths up to 120 m and with head-special-hardened (hsh) premium rail quality. The rail rolling mill Thyssen Schienen Technik in Duisburg, Germany, also belongs to the company.

The company VAE GmbH, with its headquarters in Zeltweg, Austria, is the world market 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 34 manufacturing locations in five regions (Europe, America, Australia, Africa, and Asia).

Swedish high-speed train X2 in tilting mode

PARTNERS IN EU PROJECTS

The 51 partners in our eight EU (European Union) projects during Stages 1, 2 and 3 are listed in CHARMEC's Triennial Report from Stage 3 on pages 68-69. The EU6, EU7 and EU8 projects have continued into Stage 4. For partners in our new projects EU9 and EU10, see pages 66-67 in the preceding section "Projects and results".

RESULTS AND EFFECTS IN INDUSTRY

In November-December 2006, Banverket and the partners in the Industrial Interests Group for Stage 4 have expressed the following views.

Abetong Teknik

CHARMEC has provided Abetong Teknik with an outstanding research environment. Of significant importance to the company has been the employment since 2003 of a PhD who had been trained for five years at CHARMEC, with its important network and profound knowledge in the fields of major interest to Abetong Teknik. In the past, Abetong Teknik's role as a supplier of pre-cast concrete sleeper technology only had a moderate influence on the suppliers of other track components. With its increased understanding of the interaction between the sleepers and the rest of the track structure, communication with other suppliers has been improved.

Through CHARMEC, Abetong Teknik had the opportunity to initiate a new doctoral project as well as a senior project focusing on the important interaction between the sleeper and the underlying ballast. Thanks to its role as a member of a reference group and as project co-ordinator, extra values have been gained. In a PhD project, Abetong Teknik had the possibility of involving one of the company's European licensees, which has been of great benefit for both parties. A senior project has enabled Abetong Teknik 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 hard to establish without the forum created by CHARMEC.

Abetong Teknik's participation in CHARMEC constantly provides it with better knowledge of the complex interaction between the full track structure and the running train. This knowledge is crucial when it comes to opening up discussions with other track component suppliers or railway administrations. In the long run, this should lead to overall optimization of the track structure, built up using components in harmony instead of a cluster of suboptimized components. Our improved understanding is also valuable when we adopt or reject the new ideas frequently presented within the business field of Abetong Teknik.

Banverket

CHARMEC research has helped Banverket to 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 both Banverket's and its customers' cost-effectiveness. The upgrading, for instance, of the track of the Iron Ore Line in northern Sweden from 25 to 30 tonne axle load and of 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), which use these lines for their freight. Other companies using the Swedish railways have also saved money on this investment.

During CHARMEC's Stage 4, the development of new projects dealing with track switches has been an important step forward. Today, Banverket spends about MEUR 100 annually on track maintenance, with track switches accounting for a considerable share of these costs. The present co-operation between Banverket and CHARMEC in the EU Sixth Framework Programme is expected to further this development. Another new development is a co-operative project between CHARMEC and voestalpine Bahnsysteme on switches and crossings. Other projects of great interest to Banverket deal with the improved design of concrete sleepers and insulating rail joints and also safeguarding against track buckling (sun-kinks).

Bombardier Transportation Sweden

One reason for our joining CHARMEC in 2000 was that the subsidiary Adtranz Wheelset, through which the company previously had access to the CHARMEC research results, had been sold to the Lucchini Group. The wheelset research projects dealing with rolling contact fatigue, damage and cracks have been important to the understanding of the behaviour of wheels in revenue traffic. Recently the company has been active in initiating a new CHARMEC project on wheels and rails for train speeds 250 km/h applicable to Swedish conditions with mixed traffic and a harsh climate. Furthermore, the CHARMEC work on railway noise is of great importance to the development of quieter trains. The ambitions for improving the vibrational and acoustic behaviour of trains are reflected in the fact that Bombardier has been active in the launching of new CHARMEC projects in this area. The company believes that the results will be of major importance in developing new systems and components for bogies and car bodies.

Duroc Rail

Duroc has been a member of the competence centre since 1997 and up to 30 June 2006. The subsidiary Duroc Rail is a small company which means that access to know-how and research results would not have been possible without membership of CHARMEC. In December 2005, a PhD

dissertation regarding properties of laser-clad railway steel was presented. The knowledge derived from this research, as well as from another research project dealing with the material microstructure under the cladding, has been of great importance to Duroc Rail.

The EU wants to triple the railway transportation volume, and Sweden is at the forefront in developing tracks and trains for higher axle loads. The company feels that a two-material rail is probably one of the best solutions for increasing the performance of rails and at the same time reducing noise levels. The network within CHARMEC has played a very important role in the successful EU project INFRASTAR within the Fifth Framework Programme. The rails developed in this project have now been subjected to field tests on the Iron Ore Line in northern Sweden and in the Paris underground. A partly new direction in business activities resulted in Duroc Rail leaving CHARMEC at the end of Stage 4.

Faiveley Transport

The ongoing renewal of braking systems for railway freight wagons is being 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 tests 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 EU project Euro Rolling Silently (ERS) has been of great value to the company. Faiveley Transport is now also introducing modern computerized control systems for the braking of all kinds of locomotives, wagons and coaches. The corresponding CHARMEC project addresses the extremely high level of safety and security that will be required for these systems.

Green Cargo

The co-operation with CHARMEC has been important in the evaluation of existing wheelsets and approval of new wheelset designs. The Centre's researchers have been active in developing new wheelset designs for 25 and 30 tonne axle loads, which are now being implemented by Green Cargo. Furthermore, CHARMEC has co-operated with the company in the testing and evaluation of new composition brake blocks for low noise freight transport.

Interfleet Technology

CHARMEC has provided Interfleet Technology with an outstanding research environment. This has given it a better understanding of wheel/rail contact forces, material properties, crack initiation, crack propagation, fatigue failure, brake systems etc, all of which have been of great benefit to the company's clients. Interfleet Technology has employed a PhD from CHARMEC and sees the potential of recruiting more PhDs from CHARMEC.

Lucchini Sweden

A significant achievement in co-operation with CHARMEC in recent years has been the development of new freight wagon wheelsets for 25 and 30 tonne axle loads suitable for the Nordic climate. These wheelsets need to 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. Furthermore, the CHARMEC research work at the Railway Noise Test Rig (RNTR, also on our premises) is important for the long-term strategy of developing quieter railway wheels. The CHARMEC work on out-of-round wheels has been of great benefit in the work of improving production techniques. CHARMEC personnel have also assisted in marketing and in technical meetings with customers.

Storstockholms Lokaltrafik (SL)

AB SL has been a member of the CHARMEC Competence Centre since 2003. The company believes that scientifically structured research at a high international level is crucial to the railway industry when it comes to maintaining and developing the infrastructure. Theoretical models and laboratory and in-field tests must be combined. In particular, SL has followed closely the projects "Dynamics of track switches", "Damage in track switches", "Out-of-round wheels", "Vibrations and external noise from train and track", and "Contact and crack mechanics for rails". The research results have given the company more confidence in the planning of wheel and track maintenance and in taking measures against disturbing noise from the vehicle/track system. CHARMEC's participation in international research projects and international conferences has given SL even more confidence in the company's endeavour to succeed in its efforts. Membership of CHARMEC has also provided SL with an important personal network of contacts and competence.

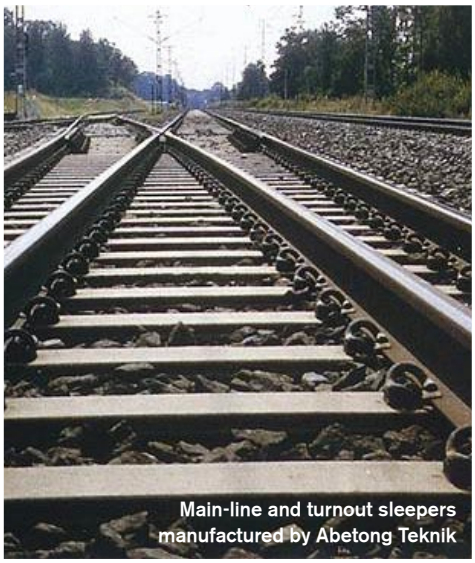
voestalpine Bahnsysteme

For voestalpine Schienen, it is very important to understand the mechanisms for crack initiation and crack growth in rails caused by the wheel/rail contact. In Stage 4, the co-operation with CHARMEC has focused on simulation models for the early growth of small cracks and also prediction of crack propagation directions. In the new Stage 5, the results of Stage 4 will be used to further develop the crack growth models and to study the interaction of rolling contact fatigue (RCF) and wear. A new focus will be on material properties and material anisotropy of used rails and the influence on RCF.

For VAE, the co-operation with CHARMEC is very important to gain a better theoretical understanding of forces, stresses and wear inside a turnout. Within Stage 4, a multibody system of a complete turnout and a finite element model of the crossing nose were developed. These models are of great importance for common future projects. They will be used to analyse and improve different turnout materials and turnout designs.


SL metro trains of type C20 on the Söderström bridge in Stockholm


Rolling of a forged Lucchini wheel


Main-line and turnout sleepers manufactured by Abetong Teknik


Bombardier's interregional train Regina

ÅKE HASSELLÖF 1925–2004

The former Managing Director of Adtranz Wheelset AB (now Lucchini Sweden AB), Åke Hassellöf, died in May 2004 at the age of 79. He took his Master of Science in Mechanical Engineering at Chalmers University of Technology in 1953, and in the same year he began working at Surahammars Bruk AB. From 1986 to 1990 he led wheelset manufacturing as Managing Director of Sura Traction AB.

Åke Hassellöf approached Chalmers Solid Mechanics and Professor Bengt Åkesson in 1987 and a first bilateral co-operation agreement was signed. This initiative by Åke Hassellöf laid the foundation for subsequent work in railway mechanics at Chalmers up to the start of the NUTEK Competence Centre CHARMEC in 1995.

SPECIAL EVENTS AND ACHIEVEMENTS

Some of the events and achievements during Stage 4 which have not been reported elsewhere will be presented.

Board meetings relocated

Three of the eleven meetings of the CHARMEC Board during Stage 4 were combined with visits to organizations outside Chalmers: on 12 November 2003 to SP Swedish National Testing and Research Institute in Borås, on 1 December 2004 to SL Infrateknik (now SL Technology) in Stockholm, and on 6 October 2005 to Ingemansson Technology in Jönköping.

VINNOVA

VINNOVA's liaison person with CHARMEC during Stage 4 was Carl Naumburg. The liaison person at Chalmers University of Technology was its Vice President for External Relations, Johan Carlsten. The final report to VINNOVA for CHARMEC's Stage 3 (1 July 2000 – 30 June 2003) was delivered on 10 December 2003.

The Director of CHARMEC, together with a number of the Centre's researchers and representatives from Banverket and the Industrial Interests Group, attended each of VINNOVA's Competence Centre Days, held on 6 November 2003 in Gothenburg, on 17 November 2004 in Stockholm, and on 2 November 2005 in Stockholm.

Impact of Competence Centres

The consultancy Technopolis in Brighton (UK) conducted interviews with universities and companies in Sweden and in July 2004 it delivered the document "Impacts of the Swedish Competence Centres: Report to VINNOVA and the Swedish Energy Agency" (149 pp). In the first instance it was the perspective of the industries involved that was considered.

The overall conclusions drawn by Technopolis are positive. Quotations from the report on the benefits of Competence Centres are: (i) substantial research productivity, with large numbers of academic outputs (papers, PhDs and so on) in addition to industrial outcomes, (ii) inspiration of research by industrial problems, generation of new knowledge and its transfer and use in industry – both established and new – to raise the rate of innovation, (iii) increased research specifically on fundamental questions of industrial relevance, in a way that is difficult to co-ordinate and exploit using other steering mechanisms, (iv) development and strengthening of the R&D networks that are core to innovation systems, (v) movement towards critical mass in R&D in some areas, and (vi) a contribution to the retention of R&D and manufacturing in Sweden by large Swedish-based firms.

Banverket's co-operation

Being a government authority and administration, Banverket could not be accepted by VINNOVA as a member of CHARMEC's Industrial Interests Group. A special agreement governing Banverket's co-operation in CHARMEC during Stage 4 was drawn up in June 2003 and was signed by Jan-Eric Sundgren, President of Chalmers University of Technology, and Bo Bylund, Director General of Banverket. The same rights and duties were assigned to Banverket as to each of the partners in the Industrial Interests Group.

KTH and SP

CHARMEC's earlier declarations of intent and agreement on co-ordination with KTH Railway Technology and SP Swedish National Testing and Research Institute were followed up during Stage 4. Following Evert Andersson's resignation from the Board in November 1999, both he and Mats Berg of KTH Railway Technology have been regularly invited to the Competence Centre's morning seminars. Roger Lundén has continued to serve on the Advisory Board of the SAMBA projects of KTH Railway Technology. Several of CHARMEC's PhD students have taken overview courses in railway technology given at KTH (The Royal Institute of Technology in Stockholm).

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 these two-page reports are edited and compiled into a document submitted to the CHARMEC Board before their next meeting when they are studied and discussed. Since 30 June 2003, all semi-annual reports have been written in English.

Project reference groups

Since Stage 3, most of CHARMEC's projects have a Project Reference Group (PRG). A PRG should be a forum for the informal presentation and discussion of results and for planning future activities (within the framework decided by the Board for the overall project plan). Mutual transfer of knowledge between researchers and industry should be furthered and implementation in industry promoted. Doctoral students should be encouraged by the PRG to

make study visits and learn about the activities of the industrial 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.

Appointment of Docents

The title Docent signifies the highest academic qualification in Sweden. To be attained, it requires approximately four years of prominent teaching and research after taking a PhD. The final pedagogic achievement of the applicant is a 'Docent Lecture'.

On 2 April 2004, CHARMEC's Jonas Ringsberg was appointed Docent with Professor Fred Nilsson of KTH Solid Mechanics as external scientific examiner. Jonas Ringsberg's Docent Lecture was entitled "Rolling contact fatigue of rails on the track". On 26 August 2005, CHARMEC's Anders Ekberg was appointed Docent with Professor Stefano Beretta of the Department of Mechanics at Politecnico Milano (Italy) as external scientific examiner. Anders Ekberg's Docent Lecture was entitled "Cracks in railway wheels – probe, predict, prevent".

Appointment of Adjunct Professor

On 1 July 2006, CHARMEC's and Epsilon HighTech's Jens Nielsen was appointed Adjunct Professor of train/track interaction. The external examiners of Jens Nielsen's scientific qualifications were Professor Evert Andersson of KTH Railway Technology and Professor David Thompson of the Institute of Sound and Vibration Research (ISVR) at the University of Southampton (UK).

Course of instruction on DIFF

On 13-14 May 2004, CHARMEC (Jens Nielsen) and Abetong Teknik (Rikard Bolmsvik) ran a course at Chalmers on the theoretical background and practical use of CHARMEC's computer program DIFF for the analysis of train/track interaction, see under projects TS1 and TS4. The participants came from Abetong Teknik in Sweden, from their licensees in South Africa and The Netherlands, and from CHARMEC.

CRC in Australia

A co-operative Research Centre for Railway Engineering and Technologies, abbreviated Rail CRC, was started in Australia in 2001 with its headquarters at Central Queensland University in Rockhampton. Roger Lundén is a member of the Technology Advisory Committee for Rail CRC. On 5-6 August 2003 and 13-14 June 2006, Roger Lundén visited Rail CRC in Australia to take part in evaluations of the standing of the Centre with regard to research quality, industrial relevance and international status.

Six Australian universities and five major railway enterprises make up Rail CRC, which was established and is supported through the Australian Government's Cooperative Research Centres Programme. The mission is formulated as follows: "To deliver valuable research, knowledge and innovation to the railway industry and its stakeholders using an internationally collaborative approach". The federal grant to Rail CRC for seven years is MAUD 11.2, corresponding to about MEUR 1.0 per year. The Chief Executive Officer of Rail CRC is Professor Dudley Roach.

Heavy haul

CHARMEC's work to support the upgrading to 30 tonne axle load on the Iron Ore Line (Malmbanan/Ofotbanen) in northern Sweden and Norway continued during Stage 4, see the CHARMEC Triennial Reports from Stages 2 and 3. We also assisted the mining company LKAB in solving problems with braking performance and wheel wear on their new iron ore wagons and locomotives, see under project MU9 on page 40.

CHARMEC researchers took part in the 8th IHHC (International Heavy Haul Conference) held on 16-18 June 2005 in Rio de Janeiro (Brazil) and presented two papers, see under projects TS8 och SD4. 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 of both NHH and IHHA. Roger Lundén is a member of the NHH Board. On 11-13 June 2007, NHH will arrange STS2007 (Special Technical Session), also named IHHA2007, in Kiruna (Sweden). CHARMEC will contribute to STS2007.

Nordic seminars on railway technology

CHARMEC researchers have contributed papers and presented their work at the annual Nordic seminars in Luleå on 1-2 June 2004 (four contributions), in Hamar, Norway, on 10-11 May 2005 (four contributions), and in Linköping on 26-27 April 2006 (six contributions). These presentations have not been listed under the CHARMEC projects.

Nordic Rail fair

CHARMEC has taken part in the 5th and 6th Nordic Rail fairs at the Elmia Exhibition Centre in Jönköping on 7-9 October 2003 and 4-6 October 2005, respectively. CHARMEC shared a stand with KTH Railway Group,

VINNOVA, the Swedish National Road and Transport Research Institute (VTI) and (at the 6th fair) Luleå Railway Research Center (JVT). At the 6th fair, our research projects were displayed on wall plates, four 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. Several valuable contacts with the railway industry were (re)established at Nordic Rail.

Swedish Mechanics Days

A two-day conference named "Svenska Mekanikdagar" (Swedish Mechanics Days) is arranged every second year and circulates among Swedish universities and institutes of technology. Several of CHARMEC's researchers have presented their results at these conferences. These contributions are not listed under the CHARMEC projects.

Overview articles

A Polish-Swedish symposium was held at Chalmers in December 2003 and one of the presentations was

> Contact mechanics and wear of rail/wheel systems – enhancing safety, environment and economy through research, by Birger Karlsson and Roger Lundén (in *Proceedings* on pp 65-69)

The Polytechnic Society of Gothenburg (Tekniska Samfundet) edits a web magazine where the December issue 2003 contained the three-page article

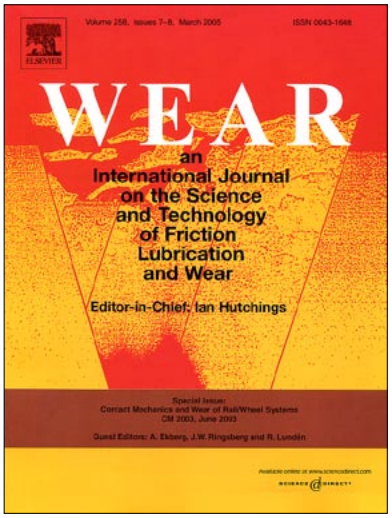
> CHARMEC – a competence centre in railway mechanics, by Anders Ekberg (in Swedish, see *www.tekniskasamfundet.org/magasinet*)

The journal Railway Gazette International celebrated its 100th anniversary in 2005 with a special issue. CHARMEC was asked to contribute with ideas for future research. They were included in the article

> Research holds the key to COMMERCIAL success, *Railway Gazette International,* vol 161, no 7, July 2005, pp 433-436

CM2003 and Wear

The 6th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2003) was arranged by CHARMEC at Chalmers on 10-13 June 2003, as described in the CHARMEC Triennial Report from Stage 3, pp 62-63. Of the 81 presentations at CM2003, 49 were submitted by the authors for publication in a Special Issue of the international scientific journal Wear. The peer review process for these articles was administered by CHARMEC, and 44 of the articles were finally accepted and are now printed in Wear, vol 258, nos 7-8, 2005, pp 953-1335, with a Guest Editorial written by CHARMEC's Anders Ekberg, Jonas Ringsberg and Roger Lundén. CHARMEC procured 200 copies of a bound reprint of these articles, which has been distributed worldwide among some of our contacts.



Front cover of Special Issue of Wear March 2005: Contact Mechanics and Wear of Rail/Wheel Systems, CM2003, June 2003

CM2006

The 7th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2006) was held in Brisbane (Australia) on 24-27 September 2006. As a result of their work during Stage 4, CHARMEC's researchers were represented through six contributions from projects TS7, TS8, TS10, MU9, MU10 and SP11, all of which had been accepted for oral presentation. CHARMEC's Roger Lundén and voestalpine Bahnsysteme's Peter Pointner also delivered a concluding plenary lecture entitled "EU Project INNOTRACK – Innovative Track Systems".

Since CM2003 in Gothenburg, Roger Lundén had served as Chairman of the Advisory Group of the International Committee for the CM conferences. This task has now been transferred to Peter Mutton of Monash University in Australia. The next conference in the series (CM2009) is due to be held in Florence (Italy). From the surplus from CM2003, Chalmers/CHARMEC made a contribution to the "CM Trust Fund".

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 have been published by CHARMEC's researchers in FFEMS, and Roger Lundén was the Guest Editor of a Special Issue of FFEMS on Wheel/Rail Safety in October 2003, see CHARMEC's Triennial Report from Stage 3, page 73.

IMechE Journal of Rail and Rapid Transit

Since 2005, Dr Simon Iwnicki of Manchester Metropolitan University (MMU) in the UK has been Editor-in-Chief of this journal (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 (30 articles up to December 2006). The abbreviation IMechE stands for The Institution of Mechanical Engineers, which has its headquarters in London (UK).

Publishing and other awards

CHARMEC's Anders Johansson and Jens Nielsen (project TS5) received the 2003 PE Publishing Award for their article "Out-of-round railway wheels – wheel/rail contact forces and track response derived from field tests and numerical simulations" in Proceedings of the Institution of Mechanical Engineers (IMechE), Journal of Rail and Rapid Transit, vol 217, no F2, 2003, pp 135-146. For the same article, they also received the Alfred Rosling Bennet Premium / Charles S Lake Award, which was presented by IMechE at their premises in Westminster / London (UK), see photo.

Award winners Anders Johansson (left) and Jens Nielsen below a portrait of George Stephenson, who founded IMechE in 1847

In July 2006, Jens Nielsen, Anders Ekberg and Roger Lundén were honoured with the IMechE Railway Division W A Agnew / C N Goodall Award for their article "Influence of short-pitch wheel/rail corrugations on rolling contact fatigue of railway wheels" in IMechE Journal of Rail and Rapid Transit, vol 219, no F3, 2005, pp 177-187.

Undergraduate students Michael Mirsch (project MU13) and Jonas Zachrisson (project TS9) received Swedtrain's Prize for Best Master's Thesis in Railway Technology in 2004 and 2005, respectively.

The Swedish National Committee for Mechanics awarded CHARMEC's Anders Johansson of project TS5 and Per Heintz of project MU12 the Folke Odqvist scholarship (grant) in 2003 and 2004, respectively.

Associated projects

Since October 2005, three railway-related research projects at the Division of Fluid Dynamics (part of the Department of Applied Mechanics) at Chalmers have been connected to CHARMEC as Associated Projects (AP). The researchers running the projects are invited to CHARMEC's seminars.

Green Train Programme

On the initiative of Banverket and Bombardier Transportation Sweden, the so-called Green Train Programme was launched in 2005 and is planned to run until 2011. A successor to the Swedish high-speed train X2 will be developed through co-operation between Banverket, Bombardier Transportation, SJ AB, Interfleet Technology, KTH Railway Technology, CHARMEC, VTI and others. The new train should have a maximum speed of 250 km/h (X2 has 200 km/h) and should be able to run on conventional Swedish track with mixed traffic in a harsh climate. Track-friendly bogies, high ride comfort and low internal and external noise levels are required. CHARMEC's Anders Ekberg and Jens Nielsen have taken part in Green Train meetings in Stockholm in September-October 2005. During CHARMEC's Stage 4, our new projects SP10 and SP11 have had a bearing on the Green Train Programme.

Banverket's FUD

CHARMEC has taken part in seminars on Banverket's programmes for Research, Development and Demonstration (Forskning, Utveckling och Demonstration, FUD). They were held in Uppsala on 31 August and 7 September 2004 and in Stockholm on 23 November 2005.

Wheel damage workshops

Workshops on wheel damage have been held in Västerås on 8 and 9 January 2004 and in Gothenburg on 8 June 2004 with the participation of Bombardier Transportation, CHARMEC and KTH Railway Technology. This activity was initiated by Bombardier Transportation Sweden.

RSSB in UK

CHARMEC has been approached repeatedly by the Rail Safety and Standards Board (RSSB) in the UK and we have submitted tenders for work in their projects. No agreements between CHARMEC and RSSB have been reached so far.

SBB and ÖBB

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

Alstom Transport

The French company Alstom Transport has approached CHARMEC to discuss possible future co-operation. Roger Lundén was invited to their headquarters in Paris on 7-8 March 2005 to make a presentation of CHARMEC. On 27 May 2005, Daniel Cadet (Director External Relations, Technical) and Thierry Fort (Technical Director Infra Division) visited CHARMEC in Gothenburg. CHARMEC's Anders Ekberg and Bengt Åkesson visited Alstom Transport's Stockholm office on 3 January 2006 and met Anders Anderberg. So far no co-operation between Alstom Transport and CHARMEC has been established.

ERWA

Ten wheelset manufacturers from eight European countries, including Lucchini Sweden, are members of the European Railway Wheels Association (ERWA), which is now the UNIFE Railway Wheels Committee. UNIFE is the Association of the European Railway Industries.

The aim of ERWA is to contribute to "improvements in wheels and wheelsets by focusing on safety, reliability and economic efficiency". The association's activities include "the definition, adaptation and implementation of advanced technology". During Stage 4, Roger Lundén continued to serve on ERWA's Technical Committee and took part in several meetings, usually held at the premises of UNIFE in Brussels (Belgium). ERWA will have overall responsibility for future International Wheelset Congresses (the 15th IWC will be held in Prague in the Czech Republic on 23-27 September 2007).

New EU projects

Chalmers/CHARMEC have been invited to be a partner in several new EU projects in railway mechanics during the Sixth Framework Programme. We have taken part in general meetings in Berlin, Brussels, Paris, Stockholm etc and also in preparing special applications. In October 2003, we signed our agreement as a partner in a Network of Excellence (NoE) named European Rail Research Network of Excellence and abbreviated EURNEX, see EU9 on page 66. Our work in the projects INFRASTAR and ERS continued into Stage 4, see EU7 on page 64 and EU8 on page 65. INNOTRACK is a large Integrated Project (IP) where CHARMEC and Banverket have been particularly active in the application procedure and have been given leading roles in this three-year project, which started in September 2006, see EU10 on page 67.

Swedish Rail Forum

CHARMEC is a member of the Swedish non-profit association Järnvägsforum (Rail Forum). It was launched in December 2002 and brings together organizations with an interest in promoting railways as an efficient, safe and environmentally friendly means of transportation. Members include major companies, research establishments, labour unions and other bodies. The Director of Järnvägsforum since the beginning has been Roger Kristenson. The chairperson since March 2005 is Monica Öhrman, former Member of the Swedish Parliament. Roger Lundén and co-workers have attended several of Järnvägsforum's seminars.

IVA railway panel

The Royal Swedish Academy for Engineering Sciences (Ingenjörsvetenskapsakademien, IVA) has had a 'railway panel' in its discussion of industrial growth in today's reregulated society in Sweden. Roger Lundén was a member of the panel and has taken part in several meetings and seminars. CHARMEC's Anders Ekberg has also contributed. Chairman of the panel was Staffan Håkansson, former CEO of Bombardier Transportation Sweden. The final IVA report "Strategi för ökad teknik- och kompetensutveckling i den svenska järnvägssektorn (Strategy for increased technical and competence development in the Swedish rail sector)" from the panel was presented at a research seminar organized by Järnvägsforum in Stockholm on 17 June 2004. An Executive Summary is to be found in the IVA Report R451 "Technical development in deregulated markets – what can we learn from the telecom, energy, railway and defence sectors" on pages 22-28.

VTI

CHARMEC researchers have taken part in the Transport Forum arranged by the Swedish National Road and Transport Research Institute (VTI) in Linköping on 14-15 January 2004, 12-13 January 2005, and 11-12 January 2006. Our contributions are not listed under the CHARMEC projects. The 24th Transport Forum will be held in Linköping on 10-11 January 2007.

Exchange with voestalpine Bahnsysteme

Twice a year during Stage 4, project leaders and researchers of CHARMEC projects TS7, MU11 and MU14 (and several other related projects) have met with their Austrian colleagues from the rail manufacturer voestalpine Schienen and the switch manufacturer VAE. To these two-day meetings, specialists were also invited from the University of Leoben (Institute of Mechanics), the Austrian Academy of Science (Erich Schmidt Institute of Materials Science), the Materials Centre Leoben, the Christian Doppler Laboratory (CDL), and the University of Munich (Department of Materials Science and Mechanics of Materials). The dates and venues during Stage 4 were 15-16 January 2004 in Leoben and Zeltweg, 27-28 May 2004 in Gothenburg, 13-14 January 2005 in Leoben and Erzberg, 7-8 June 2005 in Gothenburg, 11-12 January 2006 in Leoben and Zeltweg, and 20-21 June 2006 in Gothenburg. The next meeting will take place in Leoben and Zeltweg on 18-19 January 2007.

Guest researchers

Dr Luis Baeza of the Department of Mechanical and Materials Engineering at the Polytechnical University of Valencia (Spain) worked at Chalmers/CHARMEC in railway mechanics projects during April, May and June 2004, see reference under project TS8. Dr Paul Meehan of the Department of Mechanical Engineering at Queensland University in Brisbane (Australia) visited Chalmers/CHARMEC in May 2005 and worked with rail corrugation together with CHARMEC's Jens Nielsen and Anders Johansson. Paul Meehan's work in Brisbane is part of Australia's Rail CRC, see page 85. Several other guests to CHARMEC only worked for short periods.

External consultants and employees

It has only been partly possible to include CHARMEC's EU projects in the regular programme of studies and research for PhD students. Senior researchers have often been required at short notice to contribute to EU projects and other projects. Consequently, Chalmers/CHARMEC temporarily engaged the following, among others, as external consultants during Stage 4: Dr Hans Bjarnehed, Docent Jan Henrik Sällström, Mr Martin Helgen and Mr Markus Wallentin (both MScs), all four of Epsilon HighTech AB. Docent Jens Nielsen of Ingemansson Technology AB has worked with supervision and research for CHARMEC on a full-time basis. Dr Elena Kabo of WM-data Caran AB has worked part-time. Professor Tore Dahlberg of Linköping Institute of Technology has continued his involvement in CHARMEC projects. Anders Johansson (TS5) and Tore Vernersson (SD4) are formally employees of Epsilon HighTech AB but worked full-time at Chalmers/CHARMEC up to taking their PhDs. Docent Anders Ekberg has been an employee of Chalmers Industriteknik (CIT) since 15 April 2005 but has continued to work full-time for CHARMEC.

Some of CHARMEC's co-workers in EU projects and other projects. From the left: Martin Helgen, Tore Vernersson, Anders Johansson, Jan Henrik Sällström, Magnus Kilian and Hans Bjarnehed, all of Epsilon HighTech AB

Miscellaneous

During Stage 4, CHARMEC's personnel took part in approximately one hundred meetings and other events not specifically mentioned above. They were involved in workshops with Banverket and members of the Industrial Interests Group, minor seminars with research colleagues, invited presentations at different arrangements in Sweden and abroad etc. All these events and achievements indicate a high demand for CHARMEC's knowledge and services. Björn Paulsson and Roger Lundén, for instance, visited Pandrol in Worksop/Nottinghamshire (UK) on 15 December 2004 to discuss their rail fastenings, and Lennart Josefson took part in a Special Meeting on Damage Tolerance of Railway Axles at the GKSS Research Centre in Geesthacht/Schleswig-Holstein (Germany) on 2-3 February 2005.

FINANCIAL REPORT

Below is a presentation of cash and in-kind investments for Stage 4, both per party and per programme area. Information on the money received and used is from Chalmers' accounts for the CHARMEC Competence Centre centrally and from the accounts for each department's CHARMEC projects. The in-kind investments from the Industrial Interests Group and Chalmers have been calculated according to the principles stated in the Principal Agreement dated 19 June 2003 with VINNOVA.

Report per party

Budgeted cash and in-kind investments per party according to the Principal Agreement for Stage 4 are given in Table 1. Included are also those cash contributions from Banverket, Chalmers and VINNOVA which were not included in the Principal Agreement.

Although the Principal Agreement for Stage 4 was for three years, the financing from VINNOVA was only for the first two years. However, this funding could be used during the entire Stage 4.

Cash investments

In October/November 2003, agreements were reached between, on the one hand, each of Abetong Teknik AB, Bombardier Transportation Sweden AB, Duroc Rail AB, Green Cargo AB, Lucchini Sweden AB, SAB WABCO Group AB (now Faiveley Transport Malmö AB), SL Infrateknik AB (now AB Storstockholms Lokaltrafik), TrainTech Engineering Sweden AB (now Interfleet Technology AB) and voestalpine Bahnsysteme GmbH, respectively, and, on the other, Chalmers University of Technology AB on how the Industrial Interests Group's payments to CHARMEC should be settled. According to these nine agreements, CHARMEC would invoice at six points in time: 2003-10-01, 2004-03-01, 2004-09-01, 2005-03-01, 2005-09-01 and 2006-03-01.

A corresponding agreement was reached in June 2003 between Banverket and Chalmers University of Technology AB in which Banverket's cash investment for the three-year period is kSEK 5 400. According to this agreement, CHARMEC would invoice kSEK 900 at the six points in time specified above. In addition, Banverket would make an in-kind investment valued at kSEK 1 350.

In spring 2005, Banverket also decided to contribute the additional funding of kSEK 2 700 for Stage 4. According to an agreement reached in September 2005, CHARMEC would invoice Banverket kSEK 2 700 on 2006-03-01.

An agreement had been reached in March/April 2001 between Banverket and Chalmers/CHARMEC on the VB5 project "Wave propagations under high-speed trains" in which Banverket's cash contribution was kSEK 1 365 during Stage 3 and kSEK 385 during Stage 4. According to the agreement, CHARMEC would invoice kSEK 385 on 2003-09-01.

Table 1. Cash and in-kind contributions (kSEK) per party during Stage 4

Party	Cash		In-kind		Total	
	Budget	Paid	Budget	Performed	Budget	Paid/Perf
VINNOVA	12 625	12 625	–	–	12 625	12 625
Chalmers	4 675	4 675	18 000	18 000	22 675	22 675
Abetong	1 200	1 200	600	688	1 800	1 888
Banverket	15 865	15 865	1 350	513	17 215	16 378
Bombardier	3 000	3 000	900	821	3 900	3 821
Duroc	750	750	1 050	1 087	1 800	1 837
Faiveley	1 350	1 350	900	457	2 250	1 807
Green Cargo	720	720	480	21	1 200	741
Interfleet	150	150	150	887	300	1 037
Lucchini	1 950	1 950	1 575	1 826	3 525	3 776
SL	1 200	1 200	300	160	1 500	1 360
voestalpine	1 950	1 950	2 250	2 911	4 200	4 861
From Stage 3	437	437	–	–	437	437
TOTAL	45 872	45 872	27 555	27 371	73 427	73 243

In spring 2002, Banverket decided to contribute 50 % of the funding required for the two track switch projects TS7 and MU14, i e kSEK 450 (Stage 3) + kSEK 600 (Stage 4) and kSEK 400 (Stage 3) + kSEK 750 (Stage 4), respectively. According to agreements reached in October 2002, CHARMEC would invoice kSEK 250 + 400, kSEK 175 + 175 and kSEK 175 + 175, respectively, at the three points in time 2003-10-15, 2004-03-01 and 2004-09-01.

In spring 2004, Banverket decided to continue to contribute 50 % of the funding required for the TS7 and MU14 projects, i e kSEK 350 for each of the two projects. According to agreements reached in September 2005, CHARMEC would invoice Banverket kSEK 100 + 100 and kSEK 250 + 250, respectively, at the two points in time 2005-09-01 and 2006-03-01.

In autumn 2002, Banverket decided to contribute to a pre-study in the SP7 project "Lateral track stability" with kSEK 300 (Stage 3) + kSEK 365 (Stage 4). In autumn 2004, Banverket decided to contribute kSEK 2 500 to the SP7 project. According to an agreement reached in October 2004, CHARMEC would invoice Banverket kSEK 700, kSEK 450, kSEK 450 and kSEK 900, respectively, at the four points in time 2004-10-01, 2005-03-01, 2005-09-01 and 2006-03-01.

Another agreement was reached in March/April 2004 between Banverket and Chalmers/CHARMEC on the VB9 project "Dynamics of railway systems" in which Banverket's contribution is kSEK 1 800 during Stage 4 and kSEK 900 during Stage 5. According to an agreement reached in October 2004, CHARMEC would invoice kSEK 450 at each of the four points in time 2004-10-01, 2005-03-01, 2005-09-01 and 2006-03-01.

At its meeting on 2004-06-09, the CHARMEC Board approved a reduction in Lucchini Sweden's cash contribution from kSEK 3 000 to kSEK 1 950 and its in-kind contribution from kSEK 2 400 to kSEK 1 575 for Stage 4.

In January 2005, Banverket approved a project proposal from Interfleet Technology totalling kSEK 1 650, of which kSEK 800 was 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 November 2005, it was agreed that Banverket would contribute kSEK 300 to the SP10 project "Noise reduction measures and EU project QCITY".

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 will be paid during Stage 4 and kSEK 5 375 during Stage 5.

Chalmers University of Technology also supports its competence centres financially. During Stage 4, kSEK 1 500 was allocated to CHARMEC for the period 1 July 2003 –

Table 2. Budgeted and used cash and in-kind contributions (kSEK) during Stage 4, 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 4 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	11 550	12 174	2 750	1 722	3 765	3 340	18 065	17 236
VB	6 910	6 727	550	1 244	1 650	1 685	9 110	9 656
MU	13 375	15 448	4 175	4 343	4 455	4 660	22 005	24 451
SD	4 900	7 613	2 080	1 452	3 675	3 300	10 655	12 365
EU	1 000	1 858	–	–	555	830	1 555	2 688
SP	4 230	4 549	–	610	1 500	1 485	5 730	6 644
Management	3 900	4 475	–	–	2 400	2 700	6 300	7 175
TOTAL	45 865	52 844	9 555	9 371	18 000	18 000	73 420	80 215

Note 1 "Used" exceeding "Budget" is mainly due to consumption of the balance from Stage 3 and bilateral contributions, see Note 2

Note 2 Bilateral contributions not included in the budget: Christian Berner/Getzner Werkstoffe kSEK 150 for TS10, SBB kSEK 150 for TS10, Banverket kSEK 250 for SP8, and Banverket kSEK 233 for Management (preparation for the EU project INNOTRACK)

Note 3 The balance in cash to be transferred to CHARMEC's Stage 5 by 30 June 2006 is kSEK 45 872 – 45 865 = 7

FINANCIAL REPORT (cont'd)

30 June 2005. In spring 2005 Chalmers decided to contribute KSEK 3 175 for the period 1 July 2005 – 30 June 2006.

All amounts in cash due for CHARMEC's Stage 4 have been received as per the agreements, i e

6 × KSEK 200	Abetong Teknik
6 × KSEK 900 + KSEK 2 700 + KSEK (385 + 650 + 350 + 350 + 200 + 500 + 365 + 700 + 450 + 450 + 900 + 4 × 450 + 300 + 365) = KSEK 15 865	Banverket
6 × KSEK 500	Bombardier Transportation Sweden
6 × KSEK 125	Duroc Rail
6 × KSEK 225	Faively Transport
6 × KSEK 120	Green Cargo
6 × KSEK 25	Interfleet Technology
3 × KSEK 500 + 3 × KSEK 150	Lucchini Sweden
6 × KSEK 200	SL Infrateknik
6 × KSEK 325	voestalpine Bahnsysteme

Also received quarterly for the first two years of Stage 4 have been

8 × KSEK 1 500	VINNOVA

and a further KSEK 625 from VINNOVA for the above-mentioned projects.

Finally, 4 × KSEK 750 + KSEK 3 175 have been received from Chalmers University. The total amounts are shown in Table 1.

In-kind contributions

The in-kind contributions made by the Industrial Interests Group correspond well to the agreement for Stage 4, 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 industrial partner concerned has filled in and signed. NUTEK's guidelines as of 1995-11-07 were enclosed with the form. Salary costs (number of hours and cost per hour) 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 present report.

Report per programme area

The accounts for each individual project have been allocated funds according to budgets decided by the CHARMEC Board. A compilation by programme area is given in Table 2, where in-kind contributions are also shown.

MANAGEMENT AND ADMINISTRATION

Director	Professor Roger Lundén
Period	1997-04-01–2006-06-30 (–2009-06-30)
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 3 600
Industrial interests in-kind budget	–

Roger Lundén has devoted approximately half of his full-time position to the management and administration of the CHARMEC Competence Centre during Stage 4, the rest of his time attending to his 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 of 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 5

The Principal Agreement on CHARMEC's Stage 5 (1 July 2006 – 30 June 2009) follows VINNOVA's drawing up of the Principal Agreement on the Centre's Stage 4. However, Banverket has been included directly in the agreement and Banverket has also partly been put in the administrative role that was previously filled by VINNOVA. For the rest, the rights and duties of the three Parties, Chalmers University of Technology, Banverket and the Industrial Interests Group, are the same as those of the three Parties in the Principal Agreement on Stage 4.

In addition to the previous nine members at the end of Stage 4, the new members SJ AB and SweMaint AB have joined the Industrial Interests Group. The previous member Duroc Rail has left CHARMEC at the end of Stage 4. The programme areas in Stage 5 are the same as during Stage 4, see TS, VB, MU, SD, EU and SP on page 10.

The funding (kSEK) of Stage 5 (as of 29 November 2006) is shown in the table below. It should be noted that the ten-year funding from the national research agencies NUTEK and VINNOVA ceased on 30 June 2005.

Jan-Eric Sundgren, President of Chalmers University, signed the contracts for CHARMEC's Stage 5 on 19 June 2006. He and his successor, Karin Markides, have appointed the following as members of the Board of CHARMEC for Stage 5 (decisions dated 19 June and 15 November 2006):

Björn Paulsson (Chairman)	Banverket
Stefan Westberg	Abetong Teknik
Henrik Tengstrand	Bombardier Transportation
Roger Jönsson	Faiveley Transport
Hugo von Bahr	Interfleet Technology (and Green Cargo and SJ)
Lennart Nordhall	Lucchini Sweden
Håkan Tirus	Storstockholms Lokaltrafik
Håkan Fredriksson	SweMaint
Håkan Anderson	voestalpine Bahnsysteme
Hans Andersson	SP Technical Research Institute of Sweden
Stefan Östlund	The Royal Institute of Technology (KTH)

For photos of the new Board, see page 9

On 19 June 2006, Jan-Eric Sundgren also appointed Roger Lundén as Director of CHARMEC during Stage 5.

	Cash	In-kind	Total
Industrial Interests Group	10 770	6 780	17 550
Banverket (agreement)	10 800	1 350	12 150
Banverket (projects)	6 115	–	6 115
VINNOVA (projects)	5 675	–	5 675
Chalmers	9 750	13 500	23 250
EU*	5 096	–	5 096
UIC**	300	–	300
From Stage 4	7	–	7
TOTAL	48 513	21 630	70 143

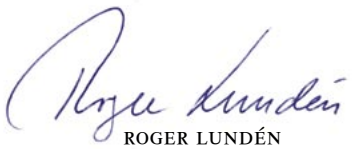
* The EU contributions do not formally belong to the CHARMEC budget

** UIC (Union Internationale des Chemins de fer/International Union of Railways) contributes to Anders Ekberg's work as Technical Co-ordinator in project EU10, see page 67

CONCLUDING REMARKS

Stage 4 of the NUTEK/VINNOVA Competence Centre in Railway Mechanics has been successful. Co-operation between the University, the Industry and Banverket has been further developed and the national and international network has been broadened. In my opinion, CHARMEC is a provider of first-rate research, a knowledgeable partner for dialogue, an important information hub and an expert network builder. Since Railway Mechanics will continue to be a key area for the development of sustainable land transport in Sweden and abroad, I look forward to the Centre's Stage 5 with confidence. Academic excellence combined with industrial relevance will continue to be our motto.

Gothenburg in December 2006



ROGER LUNDÉN

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Chalmers

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Mechanics

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