TRIENNIAL REPORT
1 July 2000 – 30 June 2003

REVIEW
1 July 1995 – 30 June 2000

PLANS
1 July 2003 – 30 June 2006

# CHARMEC

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

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Status as of December 2003

## TS

*Programme area 1*
Interaction of train and track

### TS1
**Calculation models of track structures[3]**
*Prof Thomas Abrahamsson*
*Mr Johan Oscarsson[2]*

### TS2
**Railhead corrugation formation[3]**
*Prof Tore Dahlberg[4]*
*Ms Annika Igeland[2] (now Annika Lundberg)*

### TS3
**Sleeper and railpad dynamics[3]**
*Prof Tore Dahlberg[4]*
*Ms Åsa Fenander[2] (now Åsa Sällström)*

### TS4
**Lateral track dynamics[3]**
*Prof Thomas Abrahamsson*
*Mr Clas Andersson[2]*

### TS5
**Out-of-round wheels – causes and consequences**
*Doc Jens Nielsen/Prof Roger Lundén*
*Mr Anders Johansson[1]*

### TS6
**Identification of dynamic forces in trains**
*Prof Thomas Abrahamsson/Dr Peter Möller*
*Mr Lars Nordström[1]*

### TS7
**Dynamics of track switches**
*Doc Jens Nielsen/Prof Tore Dahlberg[4]*
*Mr Elias Kassa*

### TS8
**Integrated track dynamics**
*Doc Jens Nielsen*
*Prof Tore Dahlberg[4]*

### TS9
**Track dynamics and sleepers**
*Prof Thomas Abrahamsson/Doc Jens Nielsen*
*Ms Johanna Lilja*

## VB

*Programme area 2*
Vibrations and noise

### VB1
**Structural vibrations from railway traffic[3]**
*Prof Sven Ohlsson/Prof Thomas Abrahamsson*
*Mr Johan Jonsson[2]*

### VB2
**Noise from tread braked railway vehicles**
*Prof Roger Lundén/Dr Peter Möller*
*Mr Martin Petersson[1]/Mr Tore Vernersson[1]*

### VB3
**Test rig for railway noise[3]**
*Prof Roger Lundén*
*Mr Tore Vernersson[1]*

### VB4
**Vibrations and external noise from train and track**
*Prof Roger Lundén/Dr Anders Frid/Doc Jens Nielsen*
*Mr Carl Fredrik Hartung[1]*

### VB5
**Wave propagation under high-speed trains**
*Prof Nils-Erik Wiberg*
*Mr Torbjörn Ekevid[2]*

### VB6
**Interaction of train, soil and buildings[3]**
*Dr Johan Jonsson*
*Profs Thomas Abrahamsson and Kent Gylltoft*

### VB7
**Vibration transmission in railway vehicles**
*Prof Thomas Abrahamsson/Doc Tomas McKelvey*
*Mr Per Kalling*

### VB8
**Ground vibrations from railways**
*Prof Anders Boström*
*Mr Anders Karlström*

## MU

*Programme area 3*
Materials and maintenance

### MU1
**Mechanical properties of ballast**
*Prof Kenneth Runesson*
*Mr Lars Jacobsson[1]*

### MU2
**New materials in wheels and rails[3]**
*Prof Birger Karlsson*
*Mr Johan Ahlström[2]*

### MU3
**Martensite formation and damage around railway wheel flats[3]**
*Prof Roger Lundén*
*Mr Johan Jergéus[2]*

### MU4
**Prediction of lifetime of railway wheels[3]**
*Prof Roger Lundén*
*Mr Anders Ekberg[2]*

### MU5
**Mechanical properties of concrete sleepers[3]**
*Prof Kent Gylltoft*
*Mr Rikard Gustavson[2] (now Rikard Bolmsvik)*

### MU6
**Rolling contact fatigue of rails[3]**
*Prof Lennart Josefson*
*Mr Jonas Ringsberg[2]*

### MU7
**Laser treatment of wheels and rails**
*Prof Birger Karlsson*
*Mr Simon Niederhauser[1]*

### MU8
**Butt-welding of rails**
*Prof Lennart Josefson/Dr Jonas Ringsberg*
*Mr Anders Skyttebol[1]*

### MU9
**Rolling contact fatigue of railway wheels**
*Dr Anders Ekberg/Dr Elena Kabo*
*Prof Roger Lundén*

### MU10
**Crack propagation in railway wheels**
*Prof Hans Andersson/*
*Dr Elena Kabo/Dr Anders Ekberg*
*Ms Eka Lansler*

### MU11
**Early crack growth in rails**
*Dr Jonas Ringsberg/Prof Lennart Josefson*
*Mr Anders Bergkvist*

### MU12
**Contact and crack mechanics for rails**
*Prof Peter Hansbo*
*Mr Per Heintz[1]*

### MU13
**Wheel and rail materials at low temperatures**
*Dr Johan Ahlström/Prof Birger Karlsson*

### MU14
**Damage in track switches**
*Dr Magnus Ekh/Prof Kenneth Runesson*
*Mr Göran Johansson*

### MU15
**Microstructural development during laser coating**
*Prof Birger Karlsson*
*Dr Johan Ahlström*

### MU16
**Alternative materials for wheels and rails**
*Dr Johan Ahlström/Prof Birger Karlsson*
*Mr Niklas Köppen*

## SD

*Programme area 4*
Systems for monitoring and operation

### SD1
**Braking of freight trains – a systems approach**
*Prof Göran Gerbert*
*Mr Daniel Thuresson[1]*

### SD2
**Sonar pulses for braking control[3]**
*Prof Bengt Schmidtbauer*
*Mr Hans Sandholt*

### SD3
**Computer control of braking systems for freight trains**
*Mr Håkan Edler/Prof Jan Torin*
*Mr Roger Johansson[1]*

### SD4
**Control of block braking**
*Prof Roger Lundén*
*Mr Tore Vernersson[1]*

### SD5
**Active and semi-active systems in railway vehicles**
*Prof Jonas Sjöberg*
*Ms Jessica Fagerlund*

## EU

*Programme area 5*
Parallel EU projects

### EU1
**EuroSABOT[3]**
*Prof Roger Lundén*
*Mr Tore Vernersson/Mr Martin Petersson*

### EU2
**Silent Freight[3]**
*Doc Jens Nielsen*
*Mr Martin Petersson/Mr Markus Wallentin*

### EU3
**Silent Track[3]**
*Doc Jens Nielsen*
*Mr Clas Andersson*

### EU4
**ICON[3]**
*Prof Lennart Josefson*
*Mr Jonas Ringsberg*

### EU5
**EuroBALT II[3]**
*Prof Tore Dahlberg[4]*
*Mr Johan Oscarsson*

### EU6
**HIPERWHEEL**
*Prof Roger Lundén*
*Doc Jens Nielsen/Dr Anders Ekberg*

### EU7
**INFRASTAR**
*Prof Lennart Josefson/Prof Roger Lundén*
*Doc Jens Nielsen/Dr Jonas Ringsberg/*
*Prof Birger Karlsson*

### EU8
**ERS**
*Prof Roger Lundén*
*Mr Martin Helgen/Doc Jan Henrik Sällström/*
*Mr Tore Vernersson*

## NOTES

1. Licentiate (teknologie licentiat)
2. PhD (teknologie doktor)
3. This project has been finished
4. Now at Linköping Institute of Technology

*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, see page 60)

## DEPARTMENTS INVOLVED AT CHALMERS

Applied Mechanics, Computer Engineering, Machine and Vehicle Systems, Materials Science and Engineering, Signals and Systems, Structural Engineering and Mechanics

# FOREWORD

This is a report of the organization, operation and financing of the NUTEK/VINNOVA Competence Centre CHARMEC during its Stage 3. Summaries of the research performed within the Centre are presented. A review of Stages 1 and 2 and a look forward to Stage 4 are also included. The foldout on pages 3–4 contains an overview of all CHARMEC projects since the start of the Centre on 1 July 1995. Professor emeritus Bengt Åkesson has assisted with the compilation and editing of this Triennial Report.

*Gothenburg in December 2003*

ROGER LUNDÉN
Director of CHARMEC

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

Photo: Bo Håkansson, Kamerareportage

"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


Participants in the conference CM2003 arranged by CHARMEC at Chalmers in June 2003, see page 62

# EXECUTIVE SUMMARY

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 by which they obtain access to the global railway business. – Excellent scientific achievement is evident within the six Programme Areas of* CHARMEC, *which have received attention during Stage 3.* These are two quotations from the conclusions drawn by VINNOVA's international evaluators in March 2003*.

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 3 has been MSEK 23.2 (about 2.5 million EURO). Each of three parties has contributed about one third to the financing: the University, the government research agency VINNOVA, and an Industrial Interests Group comprising 9 partners. In total, 33 research projects and 7 development projects have been run during Stage 3 within the six programme areas, see the foldout on pages 3-4 and also 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, 47 people (project leaders, academic supervisors, doctoral candidates and senior researchers) from 7 Departments in 3 Schools have been involved. They have published 90 scientific reports in international journals and conference proceedings during Stage 3. The number of licentiate's and doctor's degrees conferred during Stage 3 have been 6 and 6 respectively. A total of 21 licentiate's degrees and 13 doctor's degrees in railway mechanics have to date (December 2003) been awarded at Chalmers. More than 200 scientific reports in railway mechanics have been internationally published. The number of partners in our three new European projects during Stage 3 has been 23 (industries, universities, institutes, administrations, consultancies) from 8 countries.

CHARMEC strives at combining academic excellence and industrial relevance, generating first rate research and able PhDs. Our work includes mathematical modelling, numerical studies, laboratory experiments and full-scale in-field measurements. Co-operation with the Industrial Interests Group has been close. Transfer of knowledge in both directions has taken place through advisory groups and industrial site visits, at regular seminars and brainstorming meetings in addition to co-authored journal papers, co-ordinated conference participation and joint in-field experimental campaigns. The inertia dynamometer for braking experiments and the railway noise rig for acoustic measurements on the Lucchini Sweden plant site in Surahammar have been further developed. These activities continue into Stage 4.


International evaluators (from left) Cesar Dopazo, Robert D Fröhling, Dudley Roach, John S Baras and Per Stenius at Chalmers in March 2003

Roger Lundén at his opening of the presentation of CHARMEC before the international evaluators in March 2003

* 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), and 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.

# INTRODUCTION

*CHARMEC* is the acronym for *CHA*lmers *R*ailway *MEC*hanics. This Centre of Excellence, or Competence Centre (in Swedish: Kompetenscentrum), was established at Chalmers University of Technology in 1995. The formal agreement was made 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 sum of MSEK 20.5 was then agreed upon between NUTEK, the University and the four industrial partners Abetong Teknik, Adtranz Wheelset, Banverket and SJ. On a small scale, research in railway mechanics had started at Chalmers Solid Mechanics as early as 1987 when a first bilateral contract between Bengt Åkesson of that Department and Åke Hassellöf of Adtranz Wheelset (then Sura Traction, later ABB Sura Traction and Adtranz Wheelset, and now Lucchini Sweden) was signed.

CHARMEC's Stage 2 (1 July 1997 – 30 June 2000), which was run with a budget of MSEK 59.6, was agreed upon at a meeting in Stockholm on 10 October 1997. Cardo Rail, Duroc and Inexa Profil then joined as new industrial partners.

The agreement on CHARMEC's Stage 3 (1 July 2000 – 30 June 2003) was made at NUTEK's office in Stockholm on 22 June 2000 with a budget of MSEK 69.3, of which MSEK 43.0 was in the form of cash. In addition to the previous seven members a new member, DaimlerChrysler Rail Systems Sweden (formerly Adtranz Sweden, now Bombardier Transportation Sweden), joined the Industrial Interests Group.

At the end of this report a brief outline is given of CHARMEC's Stage 4, which runs 1 July 2003 – 30 June 2006 with a total budget of MSEK 63.4, see page 79. 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 already from 1 January 2003). The drop in the budget is explained by the fact that VINNOVA's MSEK 6.0 per annum is only paid during the first two years of Stage 4. As of 1 January 2001, VINNOVA (the Swedish Agency for Innovation Systems) has taken over responsibility for the competence centre CHARMEC.

The three parties to the agreement on CHARMEC's Stage 3 were

**Chalmers University of Technology**

**The Swedish National Board for Industrial and Technical Development (NUTEK)**

**The Industrial Interests Group**

*Abetong Teknik* – a Heidelberger Zement (now *HeidelbergCement*) Group company and concrete sleeper manufacturer with headquarters in Växjö

*Banverket* – the Swedish National Rail Administration (infrastructure authority) with headquarters in Borlänge

*Cardo BSI Rail* (now *SAB WABCO Group*) – an international manufacturer of braking systems with headquarters in Malmö

*Adtranz Sweden* (now *Bombardier Transportation Sweden*) – a train manufacturer with headquarters in Västerås

*Adtranz Wheelset* (now *Lucchini Sweden*) – a wheelset manufacturer (the only one in the Nordic countries) located in Surahammar

*Duroc* – an engineering industry and development company (specializing in surface treatments by use of laser technology) with headquarters in Umeå

*Inexa Profil* – with a rolling mill for rails in Luleå (the mill was closed down in October 2001 and the company then left CHARMEC)

*SJ* – the Swedish State Railways (rolling stock operator) with headquarters in Stockholm

As at 1 January 2001, SJ was broken up into smaller parts, of which the following two have worked as partners of CHARMEC during Stage 3:

*Green Cargo* – a railway freight operator with headquarters in Stockholm

*TrainTech Engineering Sweden* (now acquired by *Interfleet Technology*) – a consultant company specializing in railway technology

As from 1 January 2003, the Industrial Interests Group was joined by

*SL Infrateknik* – part of the regional railway administration in the Greater Stockholm area

## VISION AND GOALS

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

CHARMEC successfully unites 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 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 a continued long-term support to CHARMEC is profitable for the Government, the University and the Industry.

Among CHARMEC's concrete goals are the national training and examination of Licentiates and Doctors 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 solutions reached and the use of tools developed. CHARMEC attracts able and motivated doctoral candidates and senior researchers. The licentiates and doctors examined from CHARMEC constitute attractive employees for 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 optimizing of parts and systems for track structure and running gear is intended to result in the slower degradation of ballast and embankment, increased life of sleepers and pads, improved track alignment stability, reduced rail and wheel wear, less tendency to rolling contact fatigue of rails and wheels, lower levels of vibration and noise in trains, tracks and their surroundings, and better 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 NUTEK, appointed the following as members of the Board of the Competence Centre CHARMEC during Stage 3 (decision dated 12 September 2000):

| | |
|---|---|
| *Björn Paulsson (chairman)* | Banverket Headquarters |
| *Stefan Westberg* | Abetong Teknik |
| *Henrik Tengstrand* | Adtranz Sweden (now Bombardier Transportation Sweden) |
| *Lennart Nordhall* | Adtranz Wheelset (now Lucchini Sweden) |
| *Mats Svensson* | Cardo BSI Rail (now SAB WABCO) |
| *Mats Önner* | Duroc |
| *Olof Nilsson* | Inexa Profil |
| *Hugo von Bahr* | SJ (now TrainTech Engineering Sweden) |
| *Stefan Östlund* | The Royal Institute of Technology (KTH) |
| *Hans Andersson* | SP Swedish National Testing and Research Institute |

Later during Stage 3, Ulf Bergstedt of Duroc replaced Mats Önner (2001-04-25) and Olof Nilsson of Inexa Profil left the Board (2002-04-30).

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, now Professor Emeritus of Solid Mechanics.

Opposite page (from left):
Björn Paulsson of Banverket (chairman, 1+2+3+4)
Birgitta Johanson of Chalmers (secretary)
Roger Jönsson of SAB WABCO Group (4)
Henrik Tengstrand of Bombardier Transportation Sweden (3+4)
Håkan Tirus of SL Infrateknik (4)
Hugo von Bahr of TrainTech Engineering Sweden (1+2+3+4)
Ulf Bergstedt of Duroc Rail (3+4)
Roger Lundén of Chalmers (Director of CHARMEC)
Stefan Westberg of Abetong Teknik (1+2+3+4)
Hans Andersson of SP Swedish National Testing and Research Institute (1+2+3+4)
Lennart Nordhall of Lucchini Sweden (1+2+3+4)
Håkan Anderson of voestalpine Bahnsysteme (4)
Bengt Åkesson of Chalmers (initiator and former Director of CHARMEC)

1 = Board member Stage 1
2 = Board member Stage 2
3 = Board member Stage 3
4 = Board member Stage 4

# QUALITY ASSESSMENT AND KNOWLEDGE TRANSFER

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

- The ability to understand, formulate and "make scientific" the current problems and aims of the Industrial Interests Group
- The ability to initiate and run general future-oriented projects within the area of activity of the Centre
- 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's and doctor's degrees
- The transfer to the Industrial Interests Group of information about the results achieved and the implementation of those 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 3, the scientific quality of CHARMEC's research results has been assured through public exposure and criticism at national licentiate's seminars and defence of doctor's dissertations, as well as through presenting papers at recognized international conferences and publishing papers in recognized international journals.

The relevance of our research has been secured through discussions at the Board meetings, at the seminars at Chalmers with the industrial partners, and at frequent visits with brain-storming etc to the industrial sites. Also our participation in worldwide congresses, conferences, symposia, workshops and seminars in railway technology has 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 consultant companies, of those who gave gained licentiate's and doctor's degrees at the University.

Each individual research project within the Centre should, normally, correspond to work for a licentiate's thesis or doctor's dissertation. This is to be formulated in general terms as regards 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.

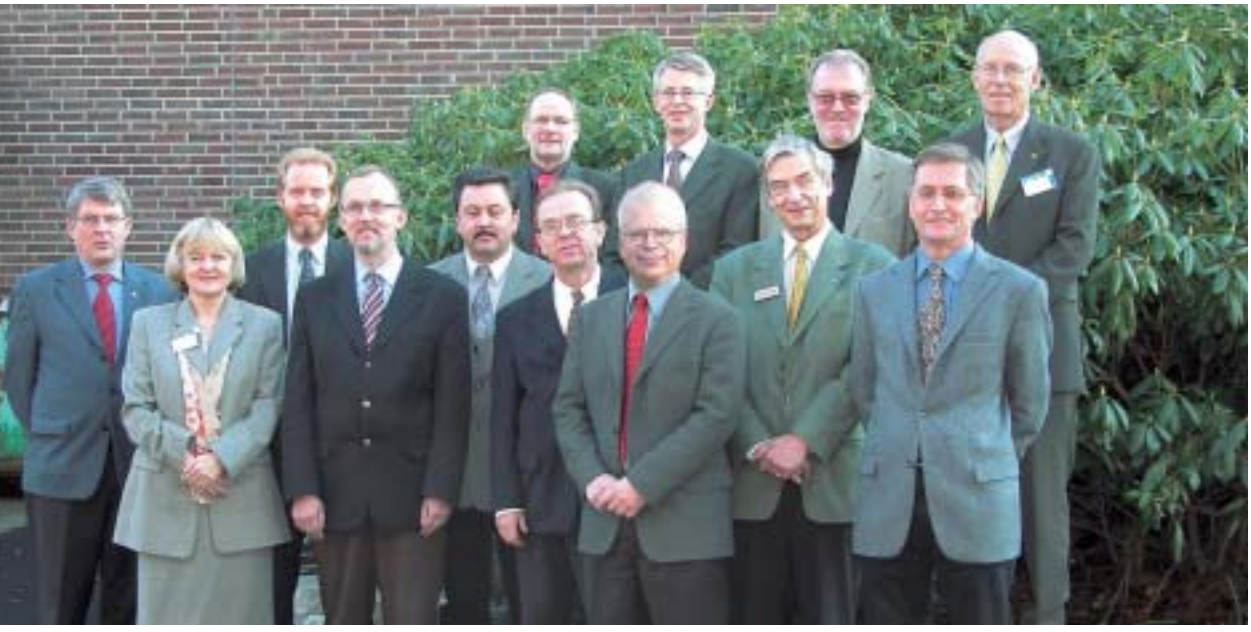


Photo: Cecilia Relam at SP during CHARMEC's Board meeting on 2003-11-12

Stefan Östlund
of KTH (2+3+4)

Mats Svensson
of Cardo Rail (3)

# PROGRAMME AREAS CHARMEC STAGE 3

According to the agreement of 22 June 2000, the Competence Centre CHARMEC should work within five overall programme areas during Stage 3, as set out below. The choice of projects within each area is decided on by the Board of the Centre. These programme areas are the same as those during Stage 2.

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

A rolling train is a mobile dynamic system that interacts, via the wheel/rail interface, with the stationary track structure, which in its turn is a dynamic system. This interaction is a key area within all railway mechanics research. The mechanisms behind vibrations, noise and wear depend on the interplay of the rolling train and the track structure. The activities of this programme area are directed towards being able to better understand, model and predict the dynamic interaction for different types and conditions of trains, tracks and operations. Theoretical, numerical and experimental methods are to be 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 for the future acceptance of this type of transportation. The generation and spreading of vibrations in trains, tracks and environment and the emission of noise are phenomena that are both theoretically and experimentally difficult to approach. The activities of this programme area are directed towards being able to better understand the underlying mechanisms. Advanced analytical and numerical tools and well-planned laboratory and in-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 embankment are a prerequisite for good mechanical performance, reduced wear, lower maintenance costs and increased technical/economic life of the components mentioned. The activities of this programme area are directed towards analysing existing materials and developing new materials. There should be created a knowledge base for the rational maintenance of train and track components. Co-operation between several different competences is 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 in what concerns its operational economy and safety. As to both passenger and freight trains, there seems to be a large potential for improvements. 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. Among them are 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 3, Chalmers University of Technology has been a partner, through CHARMEC, in several EU (European Union) projects in railway mechanics within the Fifth Framework Programme. Negotiations about our participation in EU projects within the Sixth Framework Programme have been started. All these projects are closely related to CHARMEC's ongoing research in the programme areas 1, 2, 3 and 4. CHARMEC contributes to the financing of the EU projects. It should be observed 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. The items of Stage 3 have been

- SP1 Lucchini Sweden AB (bilateral agreement)
- SP2 Noise from Swedish railways
- SP3 Track force measurements on X2
- SP4 VAE AG (bilateral agreement)
- SP5 voestalpine Schienen GmbH (bilateral agreement)
- SP6 Development of a quiet rail
- SP7 Lateral track stability

This programme area contains both short-term and long-term projects of which several have been established for the industrial implementation of CHARMEC research results.

# SUMMARY OF CHARMEC STAGE 3

Research within the Centre during Stage 3 has been carried out as planned. Two new members have joined the Industrial Interests Group. A new agreement was reached between Chalmers University of Technology and Banverket (the Swedish National Rail Administration, a government Authority) on Banverket's participation in the CHARMEC Competence Centre during Stage 3, in accordance with the main agreement with NUTEK. Ordinary Board meetings were held as follows:

| | | | | | |
|---|---|---|---|---|---|
| 21 | September | 2000 | 6 | March | 2002 |
| 29 | November | 2000 | 28 | May | 2002 |
| 20 | February | 2001 | 10 | September | 2002 |
| 5 | May | 2001 | 19 | November | 2002 |
| 5 | September | 2001 | 5 | March | 2003 |
| 6 | December | 2001 | 3 | June | 2003 |

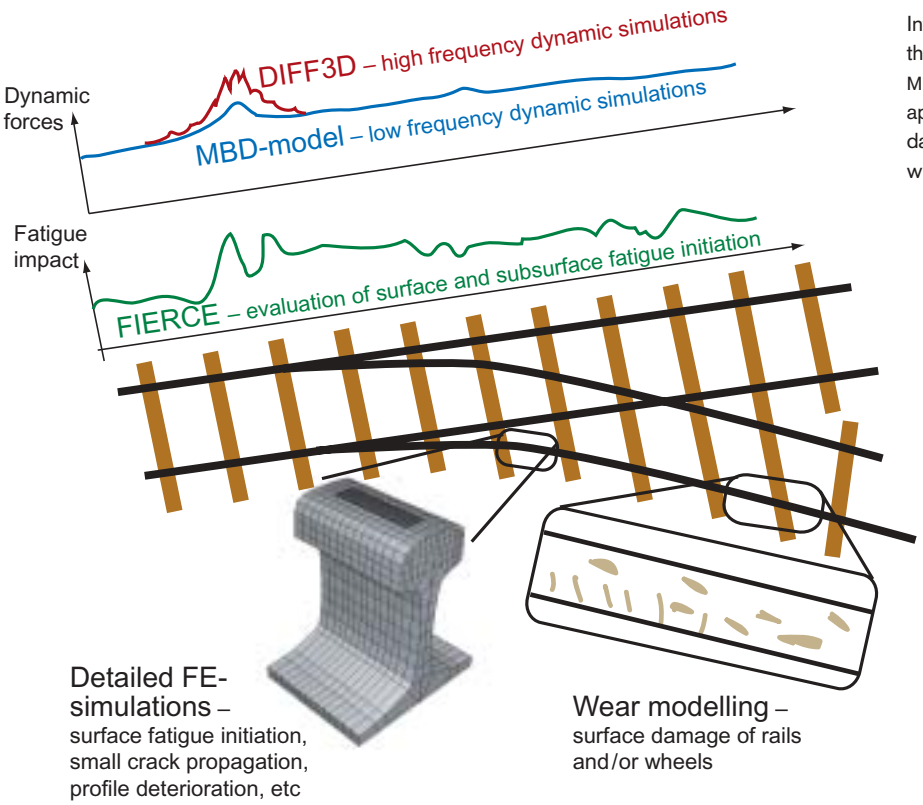
An extraordinary Board meeting (by telephone) was held on 2 October 2001 to discuss and handle the consequences of the bankruptcy and close-down of the partner Inexa Profil AB. Detailed minutes have been taken at all meetings. Early decisions were made on the content and funding of the projects carried over from Stage 2 and of new projects started during Stage 3. In addition to the five programme areas of Stage 2, one new one, "Parallel Special Projects", has been established as of Stage 3. The two full-scale outdoor test-stands in Surahammar for braking experiments and noise measurements have been further developed and used. A test campaign has been run with in-field measurements of the track forces induced by the Swedish high-speed trains of type X2.

International evaluations of CHARMEC were undertaken in March 2000 (NUTEK's report R 2000:9) and March 2003 (VINNOVA's report VI 2003:4). The latest one reviewed CHARMEC with regard to (i) the technical and scientific outcomes of the Centre, (ii) the present standing of the Centre, and (iii) the industrial benefits arising and the impact on the Centre's industrial partners. Conclusions reached by the evaluators in their written report include the following:

"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 network by which they obtain access to the global railway business."

and that :

"CHARMEC has reached over the critical mass and has established itself as an attractor for new PhD students and senior investigators. Academic indicators of excel-




Integration of research results from the CHARMEC projects TS1, TS4, MU6, MU9, MU10, EU6 etc. One application was for the remedy of damage to railway wheels during winter 2001-2002, see page 73

lence have also been met in qualitative and quantitative terms. The continued strong support of the participating industries is a sign of lively scientific and technical dynamics. Being invited to join industrial/university consortia for participation at the EU Sixth Framework Programme, attracting new industrial partners, co-operating with EU companies and being consulted by Deutsche Bahn on the 1998 high speed train accident are significant and worth mentioning distinctions."

The staff attached to the Centre, both at Chalmers (23 project leaders/principal advisers/senior researchers and 24 doctoral candidates) 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 both in increased involvement in industrial long-term knowledge development and deeper insights into the working potential of the university. Mutual learning has taken place. Two of our new PhDs have been employed by two of CHARMEC's industrial partners with the remaining four continuing at the University as senior researchers in railway mechanics. For concrete results achieved in the business activities of the industrial partners, see page 64.

Six licentiate's theses and six doctor's dissertations in railway mechanics have been presented by CHARMEC's researchers during Stage 3 up to June 2003. Furthermore, 35 articles have been published (or accepted for publication) in international scientific journals with a referee system, 55 papers have been published in the proceedings of international conferences with a referee system, several EU reports have been delivered, 25 research reports have been edited in our own series of English-language research publications (without being internationally published), 8 master's theses have been edited in our own series of student reports (in English), and several other works have been published and presented at minor seminars etc. For further information on these publications, see the lists under the projects described in the next section.

As was the case during Stages 1 and 2, 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 90 people) are invited to the seminars and to the lunch that follows. The seminars, at which all project leaders/supervisors and doctoral candidates present and discuss their projects, follow a rolling annual schedule.

The continued participation by the CHARMEC researchers in EU projects (Fourth and Fifth Framework Programmes) has expanded collaboration with industries, universities, institutes, administrations and consultancies all over Europe. CHARMEC's network linked to the EU projects comprises some 50 organizations in 9 countries; see page 68. We also co-operate with railway institutions in Australia, Canada, Japan, South Africa and USA.

A measure of the scientific standard achieved by the activities of the University and Industry at Chalmers Railway Mechanics on the international arena is the high level of acceptance of articles for journals and of contributions to conferences. In total, more than 200 such articles and contributions have thus far been internationally published. A remarkable fact is that no less than 20 articles in railway mechanics have now been published by the Chalmers/CHARMEC researchers in Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, which is a leading scientific journal in the field. A total of 21 licentiate's degrees and 13 doctor's degrees in railway mechanics have to date (December 2003) been awarded at Chalmers.

CHARMEC runs no special courses, undergraduate or graduate, in railway mechanics as such. However, a very positive consequence of CHARMEC's involvement with industrial problems has been the exposing 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, 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 master's thesis in railway mechanics.

For special events and achievements during Stage 3, see page 70. 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 already existing at Chalmers in 1994/95 could not have expanded, intramurally and extramurally, nationally and internationally, as it has now done during CHARMEC's Stages 1, 2 and 3.

# PROJECTS AND RESULTS

The publications listed under the projects are all those not previously registered in CHARMEC's Biennial and Triennial Reports 1 July 1995 – 30 June 2000 (Stages 1 and 2), 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 of them now concluded) belonged to Brite/EURAM III under the European Union's Fourth Framework Programme. The total scope of each of the EU1–EU5 projects and its partners are given in the CHARMEC Biennial Report for Stage 1. The EU6, EU7 and EU8 projects belong to the Fifth Framework Programme and are all to be found under Specific Research Programme "Competitive and Sustainable Growth" and Key Action "Land Transport and Marine Technologies". The total scope and partners in each of these projects are indicated below. Only a few of our reports related to EU projects have been listed. It should be noted that access for outsiders to EU documents supplied by us and by others is often limited.

The departments where the 46 CHARMEC projects (TS1–EU8) are being (or have been) run are listed in the following. It should here be noted that a new organization of the School of Mechanical Engineering at Chalmers University of Technology became effective by 1 July 2001. Solid Mechanics is now part of a larger Department of Applied Mechanics, Engineering Metals is included in the Department of Materials Science and Engineering, and Machine and Vehicle Design is merged into the Department of Machine and Vehicle Systems (which includes Mechatronics). As at 1 January 2003, the School of Civil Engineering has also been reorganized. Structural Engineering and Structural Mechanics are now parts of a larger Department of Structural Engineering and Mechanics.


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

# TS1. CALCULATION MODELS OF TRACK STRUCTURES

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

| | |
|---|---|
| *Project leader and supervisor* | Professor Thomas Abrahamsson, Solid Mechanics (now Applied Mechanics) |
| *Assistant supervisor* | Docent Jens Nielsen, Solid Mechanics (now Applied Mechanics) |
| *Doctoral candidate* | Mr Johan Oscarsson (from 1996-01-01; Lic Eng March 1999; PhD April 2001) |
| *Period* | 1996-01-01 – 2001-06-30 |
| *Chalmers budget (excluding university basic resources)* | Stage 1: KSEK 1400<br>Stage 2: KSEK 2000+200<br>Stage 3: KSEK 650 |
| *Industrial interests in-kind budget (Banverket)* | Stage 1: KSEK 400<br>Stage 2: KSEK 700<br>Stage 3: – |

The analysis and design of track structure, with rails, railpads, fasteners, sleepers, ballast and substructure, form an area of central interest to CHARMEC. Our earlier developed simulation model in the DIFF (Swedish acronym for Dynamic Interaction of Vehicle and Track) computer program has been expanded in the TS1 project so as better to reproduce the dynamics of the ballast and subgrade. Measured non-linearities in railpads and ballast/subgrade have been taken into consideration. DIFF has also been supplemented so that stochastic realizations of track models can be made by use of a perturbation technique. Based on the measurements in the spring of 2000 at Grundbro on the Svealand Line, it was found that the scatter in railpad stiffness makes the largest contribution to the variance of the wheel/rail contact force. See further the CHARMEC Triennial Report from Stage 2.

Johan Oscarsson successfully defended his doctoral dissertion (see below) on 20 April 2001. The faculty-appointed external examiner was Dr Søren R K Nielsen of the Department of Structural Engineering at Aalborg University in Denmark. All of the five appended papers in the dissertation have now been internationally published. Since May 2001, Johan Oscarsson has been employed by the consultancy TrainTech Engineering Sweden (now sold to Interfleet Technology Ltd) in Stockholm.


Mikael Hallqvist: Track/vehicle simulation with explicit FE-code, MSc Thesis EX 2000:5, *Chalmers Solid Mechanics,* Gothenburg March 2000, 58 pp

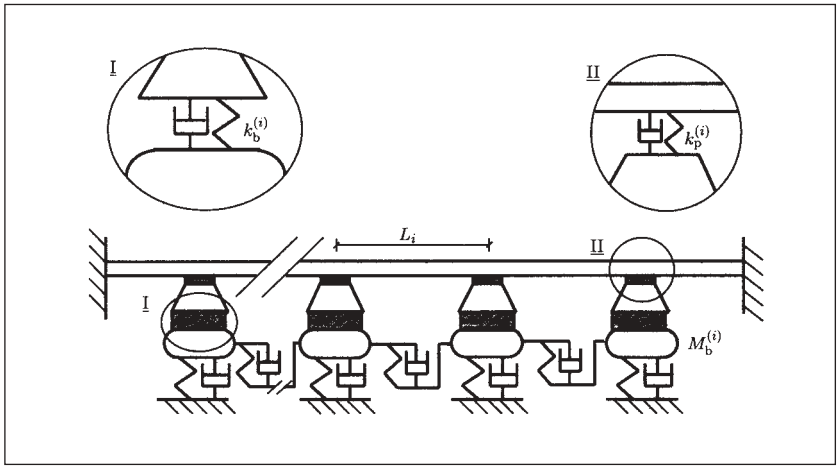
Johan Oscarsson: Dynamic train-track interaction – linear and non-linear track models with property scatter, Doctoral Dissertation, *Chalmers Solid Mechanics,* Gothenburg April 2001, 130 pp (summary and five appended papers)

Johan Oscarsson: Dynamic train-track interaction – variability attributable to scatter in the track properties, *Vehicle System Dynamics,* vol 37, no 1, 2002, pp 59-79

Johan Oscarsson: Simulation of train-track interaction with stochastic track properties, *Vehicle System Dynamics,* vol 37, no 6, 2002, pp 449-469

Johan Oscarsson: Dynamic train-track-ballast interaction with unevenly distributed track properties, *Vehicle System Dynamics,* vol 37, supplement, 2002, pp 385-396

Jens Nielsen and Johan Oscarsson: Simulation of dynamic train-track interaction with state-dependent track properties, *Journal of Sound and Vibration* (accepted for publication)


Stochastic track model in project TS1. Variables taken as having a statistical spread are pad stiffness $k_p^{(i)}$, ballast stiffness $k_b^{(i)}$, ballast mass $M_b^{(i)}$ and sleeper spacing $L_i$

Johan Oscarsson of project TS1. Photo taken 2000 in the laboratory of Chalmers Solid Mechanics

# 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) defence in public of her doctoral dissertation in January 1997, when she also left Chalmers. Tore Dahlberg (then employed as Associate Professor at Chalmers Solid Mechanics) was her supervisor. The faculty-appointed external examiner 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".

PhD student Annika Igeland of project TS2 and Dr David Thompson of ISVR at the defence of her doctoral dissertation (examination in public) in January 1997. For photo of Tore Dahlberg, see page 54

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 further the CHARMEC Biennial and Triennial Reports from Stages 1 and 2 respectively.

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

# TS3. SLEEPER AND RAILPAD DYNAMICS

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

The TS3 project was completed with Åsa Fenander's (now Åsa Sällström) 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 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 a 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 by use of fractional derivatives was explored. See further the CHARMEC Biennial and Triennial Reports from Stages 1 and 2 respectively.

PhD student Åsa Fenander (doctorate earned in May 1997) of project TS3 inspecting an instrumented wheelset in the laboratory of Chalmers Solid Mechanics. For photo of Tore Dahlberg, see page 54

# TS4. LATERAL TRACK DYNAMICS

Lateraldynamik och korrugering
Lateraldynamik der Gleiskonstruktionen
Dynamique latérale de voies ferrées

| | |
|---|---|
| *Project leader and supervisor* | Professor Thomas Abrahamsson, Applied Mechanics |
| *Assistant supervisor* | Docent Jens Nielsen, Applied Mechanics |
| *Doctoral candidate* | Mr Clas Andersson (from 1997-01-01; Lic Eng November 2000; PhD June 2003) |
| *Period* | 1998-01-01 – 2003-02-28 |
| *Chalmers budget (excluding university basic resources)* | Stage 2: KSEK 2000<br>Stage 3: KSEK 1300 |
| *Industrial interests in-kind budget (Banverket)* | Stage 2: KSEK 700<br>Stage 3: KSEK 200 |

Railhead corrugation leads to wear, vibration and noise, and the maintenance grinding of rails involves substantial costs. The mechanisms for the origin of railhead corrugation are related to concurrent vertical, lateral and longitudinal interaction between train and track in the wheel/rail interface. In the TS4 project, the DIFF calculation model (see under project TS1) has been extended to serve as a tool for the analysis of this three-dimensional interaction in the frequency range up to about 1500 Hz. Like DIFF, the new computer program works in the time domain and it has been called DIFF3D. The model of the vehicle in DIFF3D permits large rigid body movements (important to running dynamics) simultaneously with small elastic deformations of the components. The coupling to the track includes wheel/rail contact zone detection. Both elasticity and creep in the contact zone are considered. A suitable FE model of a bogie wheelset has been established. Finite elements have been used to model both the running surface of the rail and the rail as a whole. Both tangent and curved track can be investigated by use of DIFF3D.

The experimental basis of the track model has been developed in full-scale measurements in co-operation with Banverket at Grundbro on a stretch of tangent track of the Svealand line. Direct and cross accelerances for rails in vertical and lateral directions were registered.

Dr Clas Andersson (right) and Professor Thomas Abrahamsson of project TS4

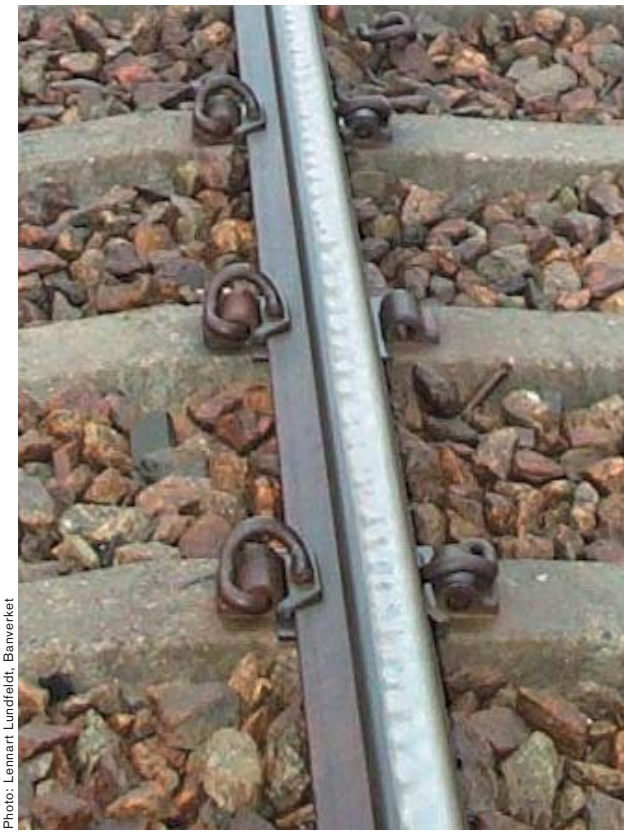
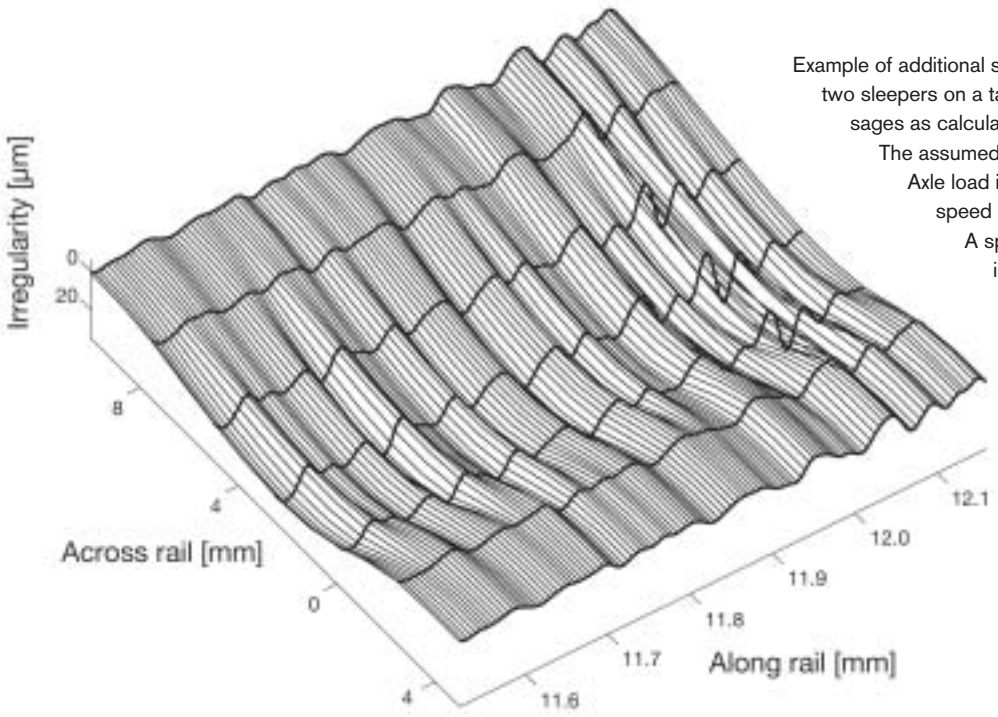


Photo: Lennart Lundfeldt, Banverket

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

## TS4. (cont'd)




Example of additional surface wear on the railhead between two sleepers on a tangent track after 7×10000 bogie passages as calculated for a driven wheelset in project TS4. The assumed initial roughness is seen at the edges. Axle load is 200 kN, driving torque 9200 Nm, train speed 130 km/h and friction coefficient 0.30. A spectral analysis shows that the increase in roughness mainly occurs at two wavelengths: about 40 mm and 60 mm

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. An efficient time-stepping method for reducing simulation times has been developed. See further the CHARMEC Triennial Report from Stage 2.

The presentation and defence of Clas Andersson's doctoral dissertation (see below) took place on 4 June 2003. Professor Mats Berg of the KTH Railway Group served as the faculty-appointed external examiner. From March to December 2003, Clas Andersson is assisting Elias Kassa in the TS7 project.

Clas Andersson and Thomas Abrahamsson: Simulation of interaction between a train in general motion and a track, *Vehicle System Dynamics,* vol 36, no 6, 2002, pp 433-455

Clas Andersson and Thomas Abrahamsson: A partitioned time integration approach for coupled systems in dynamics, *Chalmers Applied Mechanics,* Gothenburg 2002, 24 pp (submitted for international publication)

Clas Andersson: Vertical and lateral track dynamics – measurements, model and calibration, Research Report 2003:2, *Chalmers Applied Mechanics,* Gothenburg 2003, 38 pp

Clas Andersson and Anders Johansson: Prediction of rail corrugation generated by three-dimensional wheel-rail interaction, Research Report 2003:4, *Chalmers Applied Mechanics,* Gothenburg 2003, 28 pp (submitted for international publication)

Clas Andersson: Modelling and simulation of train-track interaction including wear prediction, Doctoral Dissertation, *Chalmers Applied Mechanics,* Gothenburg 2003, 163 pp (summary and five appended papers)

Clas Andersson after his successful defence of the doctoral dissertation. The other persons from right: Professor Mats Berg (external examiner), Professor Thomas Abrahamsson (chairman of the ceremony), and Professors Olof Friberg, Peter Göransson and Jonas Sjöberg (grading committee)

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

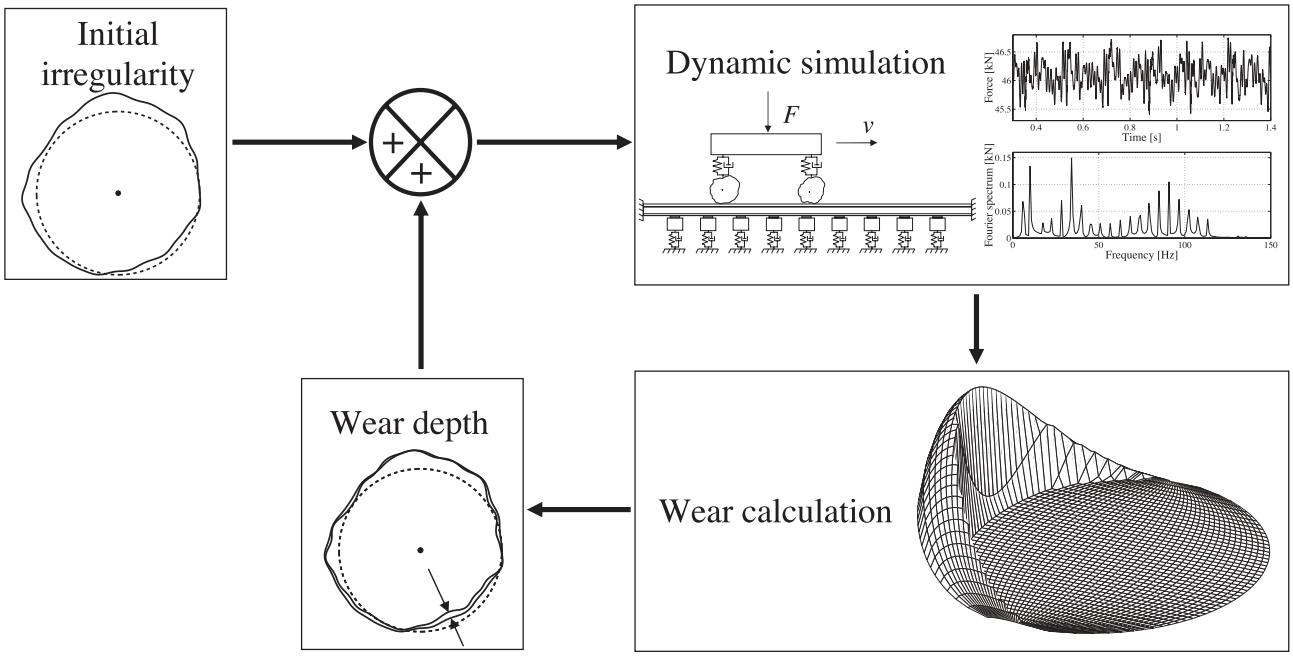
Orunda hjul – orsaker och konsekvenser
Unrunde Räder – Ursachen und Konsequenzen
Défaults de rondeur des roues – causes et conséquences

| | |
|---|---|
| *Project leader and supervisor* | Docent Jens Nielsen, Applied Mechanics |
| *Assistant supervisor* | Professor Roger Lundén, Applied Mechanics |
| *Doctoral candidate* | Mr Anders Johansson, (from 2000-08-01; Lic Eng September 2003) |
| *Period* | 1998-05-01 – 2003-06-30 (– 2005-06-30) |
| *Chalmers budget (excluding university basic resources)* | Stage 2: KSEK 1300+150<br>Stage 3: KSEK 2150+850+200+100<br>Stage 4: KSEK 1300+600 |
| *Industrial interests in-kind budget* | Stage 2: KSEK 300+200+100 *(Banverket+SJ+Duroc)*<br>Stage 3: KSEK 300+100+50 *(Banverket+Duroc+TrainTech)*<br>Stage 4: KSEK 100+100+50 *(Banverket+Duroc Rail+TrainTech)* |

Railway traffic with out-of-round wheels leads to increased dynamic stresses in both track and vehicle with fatigue fracture as the most serious consequence. In the TS5 project, the causes and consequences of long-wave out-of-roundness (OOR) of the wheel tread (from only one wave up to a total of five waves around the circumference of the wheel) constitute the primary subject of investigation. Both field studies and numerical simulations are being performed. A database of the most frequent wheel damage in Sweden is to be established with regard to wheel type, train speed, axle load and type of traffic. One of the objectives in the project is to determine which amplitudes and wavelengths in the OOR are important in the interaction between train and track, and to study how these should relate to appropriate criteria in wheel damage detectors. It should be possible to set limits for permissible OOR and propose measures for counteracting OOR. The project was started during 1998-1999 with a comprehensive study of the literature, see reference in the CHARMEC Triennial Report from Stage 2.

The full-scale tests with a freight train provided with a number of deliberate types of wheel damage (wheel flats, local spalls, periodic OOR, long local defects) took place in the spring of 2000 at Grundbro on the Svealand Line. These have now been evaluated and used for calibration of a mathematical model. The tests were carried out in co-operation with Banverket, SJ and Adtranz Wheelset (now Lucchini Sweden). Two different axle loads were studied in combination with speeds in the range 30 to 100 km/h.

Wheel polygonalization in the Stockholm subway has also been investigated assuming straight track. Through numerical simulations, important "wavelength-fixing mechanisms" of wheel OOR have been determined. These are the P2-resonance (wheelset, rail and sleepers vibrating in phase on the ballast/subgrade) and a vertical antiresonance of the track. Unfortunately, the predicted



## TS5. (cont'd)

irregularities do not resemble the measured OOR. It is therefore now assumed that some other damage mechanism(s) may be present, such as damage caused by the traction system or the tread braking system. Future simulations will include axle flexibility, curved track and varying irregularities on the different wheels.

Anders Johansson gained his Licentiate of Engineering on 5 September 2003. At the licentiate seminar, the discussion was introduced by Dr Sebastian Stichel of the KTH Railway Group. The TS5 project has a reference group with members from Banverket, Bombardier Transportation and TrainTech Engineering.


Anders Johansson and Jens Nielsen: Railway wheel out-of-roundness – influence on wheel-rail contact forces and track response, *Proceedings 13th International Wheelset Congress,* Rome (Italy) September 2001, 9 pp on CD. At the conference this work was awarded the prize for best paper in the category "Wheel-Rail Contact"

Anders Johansson and Jens Nielsen: Out-of-round railway wheels – wheel-rail contact forces and track response derived from field tests and numerical simulations, *IMechE Journal of Rail and Rapid Transit,* vol 217, no F2, 2003, pp 135-146

Anders Johansson: Mathematical models for simulation of wheel-rail rolling contact and for prediction of wheel wear – survey of models for calculation of creep forces, spin moments and wear depths, Research Report 2003:3, *Chalmers Applied Mechanics,* Gothenburg 2003, 42 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, Research Report 2003:5, *Chalmers Applied Mechanics,* Gothenburg 2003, 38 pp

Jens Nielsen, Roger Lundén, Anders Johansson and Tore Vernersson: Train-track interaction and mechanisms of irregular wear on wheel and rail surfaces, *Vehicle System Dynamics,* vol 40, nos 1-3, 2003, pp 3-54. Also presented as an invited Keynote Lecture at *18th IAVSD Symposium, Dynamics of Vehicles on Roads and Tracks,* Atsugi, Kanagawa (Japan) August 2003

Anders Johansson and Clas Andersson: Out-of-round railway wheels – study of formation of long periodic defects by combining analysis of wear and dynamic train-track interaction, *18th IAVSD Symposium, Dynamics of Vehicles on Roads and Tracks,* Atsugi, Kanagawa (Japan) August 2003, Extensive Summaries, pp 291-293

Anders Johansson: Out-of-round railway wheels – literature survey, field tests and numerical simulations, Licentiate Thesis, *Chalmers Applied Mechanics,* Gothenburg September 2003, 87 pp (summary and three appended papers)


← Iterative scheme for coupling of dynamic train/track interaction and wear when calculating the increase in out-of-roundness in project TS5

PhD students Anders Johansson (centre) in project TS5 and Elias Kassa (left) in project TS7 with their supervisor Docent Jens Nielsen. Photo taken at the SweMaint maintenance shop in Gothenburg

Measurement in project TS5 of wheel out-of-roundness on powered wheelset of a regional train as performed in October 2002 by the Danish consulting firm Ødegaard & Danneskiold-Samsøe A/S at Bombardier Transportation in Västerås. Three mechanical probes, 10 mm axially apart, follow the tread surface while the wheelset is slowly rotated by hand

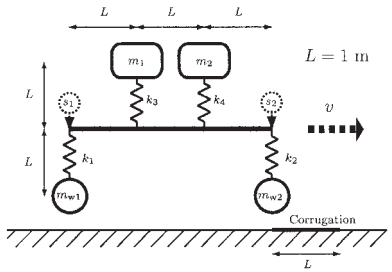
# TS6. IDENTIFICATION OF DYNAMIC FORCES IN TRAINS

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) |
| *Period* | 2000-07-01 – 2003-06-30 (– 2005-08-31) |
| *Chalmers budget (excluding university basic resources)* | Stage 3: KSEK 2150<br>Stage 4: KSEK 1300 |
| *Industrial interests in-kind budget (Bombardier Transportation)* | Stage 3: KSEK 400<br>Stage 4: KSEK 300 |

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

The general aim of the TS6 project is to study, on a broad scale, possible methods for calculation of forces acting at locations inaccessible for direct measurements. A solution to a so-called inverse problem is sought. Starting from a




Two-dimensional generic vehicle model as used in project TS6

basis of measured accelerations and other responses in appropriate positions and directions on board a running wagon, new attempts will be made to determine the exciting contact forces on the wagon wheels. Internal forces in a running vehicle may also be identified. This will require a very good system description of the wagon based on both mathematical modelling and experimental measurements, together with certain a priori assumptions.

The practical possibilities of performing load measurements by means of indirect methods will be elucidated. In an extension of the project, sensors may be supplemented by actuators to introduce an active mechatronic control system to increase, for example, riding comfort in a passenger coach in real time. By using conditions that are specific to moving vehicles, it may be possible to identify the causes of the time-variance of the registered contact forces, i e irregularities on wheels and tracks. A project plan dated 2000-09-11 was approved by the CHARMEC Board on 21 September 2000.

Dynamic Programming (DP), Sum of Weighted Accelerations Technique (SWAT), Inverse Structural Filtering (ISF), Partial Modal Matrix Technique (PMM) and Wavelet Parametrization Method (WPM) are methods for load identification that have been studied, implemented and evaluated. Several numerical experiments have been performed. Emphasis has been placed on DP for linear time-variant systems. Discussions with Bombardier Transportation have resulted in the design and construction of a test rig for measurement of contact forces on non-rotating wheelsets. The rig has been installed in the laboratory of Chalmers Applied Mechanics, see photo. It is planned that the rig will be supplemented so that measurements can be performed on a wheelset rotating at low speed.

Lars Nordström gave his licentiate seminar (see below) on 24 January 2003. The discussion was introduced by Mr Svante Karlsson, Licentiate of Engineering, of Volvo Powertrain AB. The reference group of the TS6 project has members from Banverket, Bombardier Transportation, KTH and TrainTech Engineering. The work in TS6 is co-ordinated with that in the projects VB7 and SD5.

Christophe Deventer: Structural load identification with experimental evaluation, MSc Thesis EX2001:8, *Chalmers Applied Mechanics,* Gothenburg 2001, 81 pp

Lars Nordström and Patrik Nordberg: A critical comparison of time domain load identification methods, *Proceedings 6th International Conference on Motion and Vibration Control (MOVIC 2002),* Saitama (Japan) August 2002, vol 2, pp 1151-1156

Lars Nordström and Patrik Nordberg: A time delay method to solve non-collocated input estimation problems (submitted to *Mechanical Systems and Signal Processing*)

Lars Nordström: Load identification using time domain methods, Licentiate Thesis 2003:1, *Chalmers Applied Mechanics,* Gothenburg 2003, 57 pp (summary and two appended papers)

Johanna Lilja: Identification of a finite element railway wheelset model, MSc Thesis EX2003:6, *Chalmers Applied Mechanics,* Gothenburg 2003, 58 pp

From left: PhD student Lars Nordström, Master's student Johanna Lilja and the supervisors Professor Thomas Abrahamsson and Dr Peter Möller in project TS6. Photo taken at wheelset test rig in the laboratory of Chalmers Applied Mechanics →

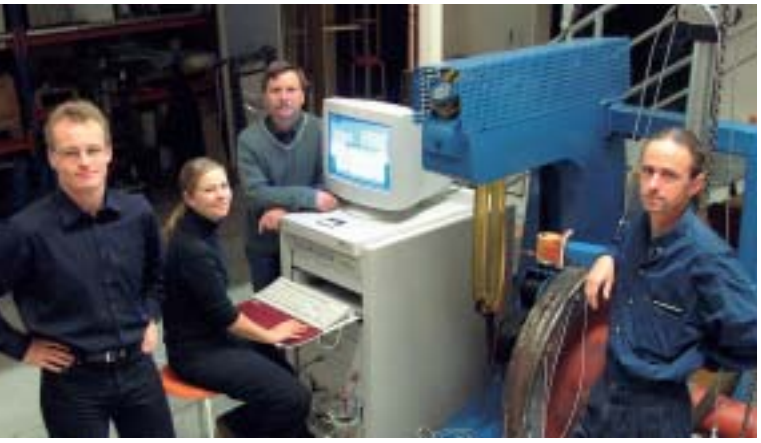
# TS7. DYNAMICS OF TRACK SWITCHES

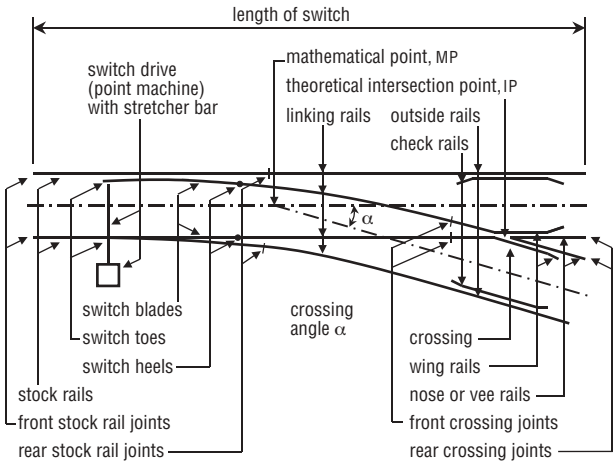
Spårväxlars dynamik
Dynamik von Eisenbahnweichen
Dynamique des aiguilles de voies ferrées

| | |
|---|---|
| *Project leader and supervisor* | Docent Jens Nielsen, Applied Mechanics |
| *Assistant supervisor* | Professor Tore Dahlberg, Linköping Institute of Technology |
| *Doctoral candidate* | Mr Elias Kassa, MSc (from 2002-04-01) |
| *Period* | 2002-04-01 – 2003-06-30 (– 2007-03-31) and a prestudy 2001-06-01 – 2002-06-30 |
| *Chalmers budget (excluding university basic resources)* | Stage 3: KSEK 500+750+500<br>KSEK 250 *(VAE)*<br>Stage 4: KSEK 2050+100+300 |
| *Industrial interests in-kind budget* | Stage 3: KSEK 200 *(Banverket)*<br>Stage 4: KSEK 300+200+600 *(Banverket+SL Infrateknik +voestalpine Bahnsysteme)* |

*For photos of Jens Nielsen, Tore Dahlberg and Elias Kassa, see pages 19 and 54*

A basic understanding will be obtained in the TS7 project of how railway switches (turnouts, see figure caption below) should be developed in order to obtain lower maintenance costs, fewer traffic disruptions and longer inspection intervals. Mathematical models for simulation of the dynamic interaction between the running train and a switch will be developed. These models will be used to find the contact forces and to determine where in the switch and crossing panels contact between wheels and rails takes place. The effects of geometrical design, manufacturing tolerances and operational wear on the performance will be investigated. The simulations will be calibrated and validated by use of in-field measurements.






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, for instance 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 switching, closure and crossing panels. Switches are sometimes referred to as "points"

A project plan dated 2002-02-21 was approved by the CHARMEC Board on 6 March 2002. A prestudy has been performed, see below. For the period up to 2003-06-30, the project had a direct contribution to its financing from VAE AG, see SP4 on page 59. The usage of the terms switch, turnout and points varies, see figure above.

Preliminary studies of low-frequency interaction between a train and a switch (turnout) have been conducted using the commercial software GENSYS. Contact between wheel back-flange and check rail (guard rail) has been accounted for. Study visits in the field have been made to increase understanding of how railway switches are designed, built and maintained and to learn about common defects. The switch UIC60-760-1:15 has been selected as a reference design to be investigated in detail. Dr Clas Andersson is assisting in the project from March to December 2003.

The joint TS7/MU14 reference group met at Chalmers on 25 February and 13 November 2003 with participants from Abetong Teknik, Banverket, Linköping Institute of Technology (LiTH), Luleå Technical University (LTU), Storstockholms Lokaltrafik (SL) and the Austrian companies VAE AG and voestalpine Schienen GmbH.

Jan Henrik Sällström (editor), Tore Dahlberg, Magnus Ekh and Jens Nielsen: State-of-the-art study on railway turnouts – dynamics and damage/Förstudie om spårväxlar – dynamik och slitage (both English and Swedish version), Research Report 2002:7, *Chalmers Applied Mechanics,* Gothenburg 2002, 50 pp

Jan-Henrik Sällström: Railway switches in Sweden – research towards enhanced reliability and maintenance, *Proceedings International Railway Conference on Switches and Crossings,* Delft (the Netherlands) March 2002, 18 pp on CD

## TS8. INTEGRATED TRACK DYNAMICS

Integrerad spårdynamik
Integrierte Gleisdynamik
Dynamique intégrée de la voie

| | |
|---|---|
| *Project leader* | Docent Jens Nielsen, Applied Mechanics |
| *Co-worker* | Professor Tore Dahlberg, Linköping Institute of Technology |
| *Period* | 2003-10-01 – 2006-06-30 |
| *Chalmers budget (excluding university basic resources)* | Stage 4: KSEK 1500 |
| *Industrial interests in-kind budget* | Stage 4: KSEK 500+100 *(Banverket+Abetong Teknik)* |

*For photos of Jens Nielsen and Tore Dahlberg, see pages 19 and 54*

A general tool for the rational design of the track and its components will be established in the TS8 project based on the results of earlier and new research. One aim is to broaden the application of our computer programs DIFF and DIFF3D better to handle frequencies below 50 Hz. New long-term and recurrent measurements of track stiffness and rail roughness are foreseen. A model for track settlements will be integrated with DIFF. The behaviour of the traditional monobloc sleeper will be compared to that of so-called twin-block, ladder, winged and booted sleepers and to that of a slab-track. A project plan dated 2003-06-02 was approved by the CHARMEC Board on 3 June 2003. It is planned that only senior researchers be engaged in the TS8 project.



## 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 Docent Jens Nielsen, Applied Mechanics |
| *Doctoral candidate* | Ms Johanna Lilja, MSc (from 2004-02-09) |
| *Period* | 2004-01-01 – 2006-06-30 (– 2008-12-31) |
| *Chalmers budget (excluding university basic resources)* | Stage 4: KSEK 1825 |
| *Industrial interests in-kind budget (Abetong Teknik)* | Stage 4: KSEK 500 |

*For photos of Thomas Abrahamsson, Jens Nielsen and Johanna Lilja, see pages 16, 19 and 21*

The TS9 project will focus on the design loads for a sleeper installed in a track carrying different types of railway traffic. The results from earlier CHARMEC projects will be exploited and new in-field measurements performed. Important issues are the true contact load on the sleeper from the ballast, the influence of ballast settlements and the optimal shape of a sleeper. It is planned that a stochastic approach to the modelling of subgrade, ballast and traffic be used and that a probabilistic design method for sleepers be developed. The required statistical properties will be deduced from test data. An optimization may be carried out by use of DIFF (see under project TS1), which will be further developed to handle stochastic variations. A project plan dated 2003-06-02 was approved by the CHARMEC Board on 3 June 2003.

PhD student Martin Petersson of project VB2 (see next page). Photo taken 2000

# VB1. STRUCTURAL VIBRATIONS FROM RAILWAY TRAFFIC

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

*For photo of Johan Jonsson, see page 28*

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

An important conclusion from the VB1 project was that only low-frequency vibrations are effectively transmitted through the ground into a nearby building foundation from a passing train. 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 ca 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 further the CHARMEC Biennial and Triennial Reports from Stages 1 and 2 respectively.



# 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 |
| *Doctoral candidates* | Mr Tore Vernersson (March 1994 to December 1997; Lic Eng September 1997) |
| | Mr Martin Petersson (from January 1998; Lic Eng October 1999) |
| *Period* | 1995-07-01 – 2001-06-30 |
| *Chalmers budget (excluding university basic resources)* | Stage 1: KSEK 700<br>Stage 2: KSEK 900<br>Stage 3: KSEK 325 |
| *Industrial interests in-kind budget (Adtranz Wheelset/ Lucchini Sweden)* | Stage 1: KSEK 600<br>Stage 2: KSEK 900<br>Stage 3: KSEK 200 |

*Note: VB2 has been part of a larger project with parallel funding direct from Adtranz Wheelset (now Lucchini Sweden, see SP1 on page 58).*

Freight trains run to a large extent at night, and have moreover 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 and dynamic 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 the VB2 project is to understand the mechanisms behind the growth of tread corrugation and to try to reduce this.

Extensive braking experiments have been performed in the test rig (inertia dynamometer) at Surahammar, see page 50, and mathematical modelling and numerical simulations have been 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 and 2 respectively.

The completion of the VB2 project is delayed. Martin Petersson has left Chalmers for employment elsewhere. CHARMEC's financial contribution to the project ended by 30 June 2001. It is planned, however, that Martin Petersson should complete his doctoral dissertation. Two new reports (to be included in the dissertation) have been published during Stage 3.

Martin Petersson: Two-dimensional finite element simulation of the thermal problem at railway block braking, *IMechE Journal of Mechanical Engineering Science,* vol 216, no C3, 2002, pp 259-273

Martin Petersson and Tore Vernersson: Noise-related roughness on tread braked railway wheels – experimental measurements and numerical simulations, *Wear,* vol 253, nos 1-2, 2002, pp 301-307 (revised version of conference paper)

# 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 finished by 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 built outdoors on the Adtranz Wheelset (now Lucchini Sweden) factory site at 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 further the CHARMEC Biennial and Triennial Reports from Stages 1 and 2 respectively.

PhD students Tore Vernersson (left) and Carl Fredrik Hartung (right) with their project leader and supervisor Professor Roger Lundén in projects VB3 and VB4. Photo taken 2000

Railway Noise Test Rig (RNTR) on the premises of Lucchini Sweden at Surahammar

# 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)<br>Docent Jens Nielsen, Applied Mechanics |
| *Doctoral candidate* | Mr Carl Fredrik Hartung (from 1999-04-01; Lic Eng November 2002) |
| *Period* | 1998-07-01 – 2003-06-30 (– 2006-06-30) |
| *Chalmers budget (excluding university basic resources)* | Stage 2: KSEK 1200<br>Stage 3: KSEK 1950<br>Stage 4: KSEK 800 |
| *Industrial interests in-kind budget* | Stage 2: KSEK 200+200+200 *(Abetong Teknik+Adtranz Wheelset+SJ)*<br>Stage 3: KSEK 300+600 *(Bombardier Transportation +Lucchini Sweden)*<br>Stage 4: KSEK 100+600 *(Bombardier Transportation +Lucchini Sweden)* |

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. A squealing or screeching sound is emitted when the wheels slide against the rails on curves. This sound can also come from the contact between brake block and wheel tread. The VB4 project is to use and develop 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. Tore Vernersson has contributed to the project.

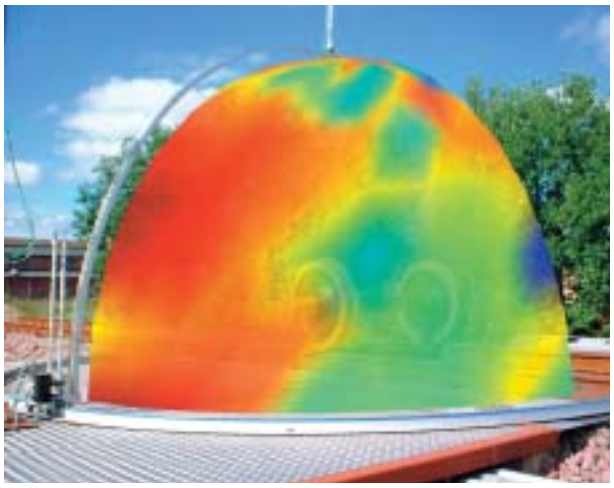
The properties of the RNTR have been compared with results from in-field measurements on a standard Swedish line. The track model in the commercial computer program TWINS has been validated by use of measured data from RNTR and from the real track with a high degree of concordance in the frequency range 500-5000 Hz. The results of measurements on RNTR and calculations with TWINS have been compared, for both wheel and rail, with respect to the directivity of the noise radiation, the frequency spectrum of the noise output and the total noise output. Noise radiation for both a "unity roughness" and a realistic irregularity spectrum of the roughness in the wheel/rail contact has been studied. The noise outputs from RNTR and TWINS show a high level of consistency when it comes to the shape (but not level) of the 1/3 octave band spectrum. Work is continuing to find the reason for the discrepancy.

Carl Fredrik Hartung gave his licentiate seminar (see below) on 22 November 2002. Dr Hans Jonasson of the Acoustic Laboratory at SP Swedish National Testing and Research Institute introduced the discussion. The VB4 project has been partially discontinued (prematurely) and Carl Fredrik Hartung left Chalmers by November 2002.

Carl Fredrik Hartung and Tore Vernersson: A full-scale test rig for railway rolling noise – simulation and measurements of dynamic wheelset-track interaction, *Proceedings 7th International Workshop on Railway Noise (IWRN),* Portland ME, USA, October 2001/*Journal of Sound and Vibration,* vol 267, no 3, 2003, pp 549-563

Carl Fredrik Hartung: A full-scale test rig for railway rolling noise, Licentiate Thesis 2002:3, *Chalmers Applied Mechanics,* Gothenburg November 2002, 68 pp (summary and two appended papers)

Carl Fredrik Hartung, Anders Frid and Jens Nielsen: Railway rolling noise emission from wheel and track – simulations and full-scale test rig measurements, *Proceedings 10th International Congress on Sound and Vibration (ICSV10)*, Stockholm (Sweden) July 2003, 8 pp



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

# VB5. WAVE PROPAGATION UNDER HIGH-SPEED TRAINS

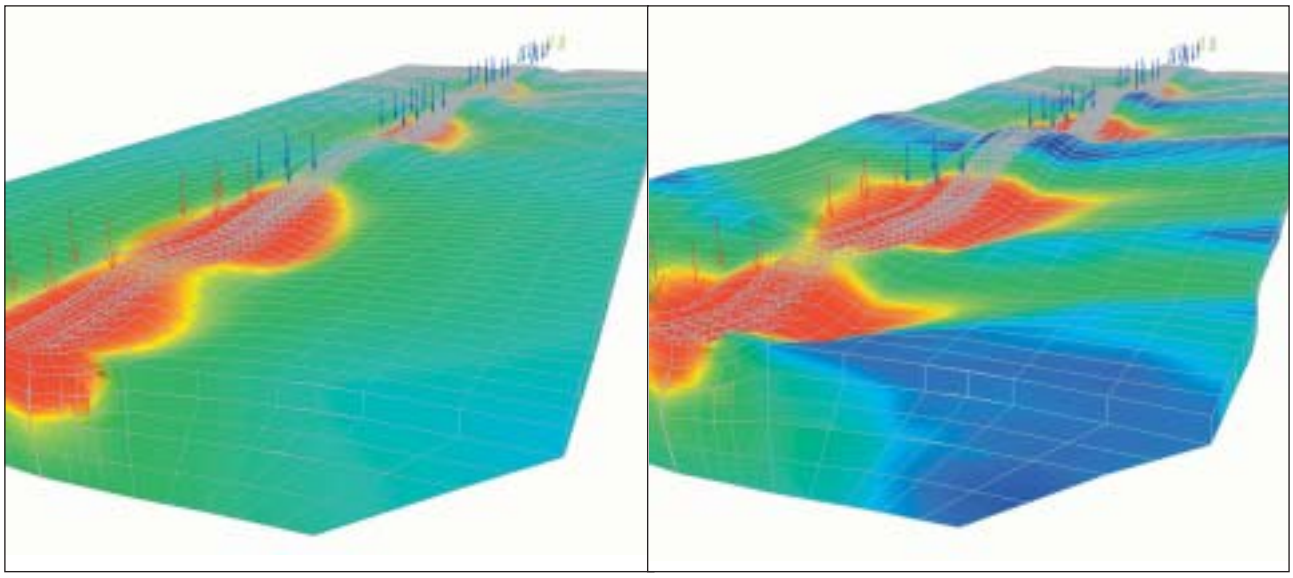
Vågutbredning under höghastighetståg
Wellenausbreitung unter Hochgeschwindigkeitszügen
Propagation d'ondes sous des trains à grande vitesse

| | |
|---|---|
| *Project leader and supervisor* | Professor Nils-Erik Wiberg, Structural Mechanics |
| *Doctoral candidate* | Mr Torbjörn Ekevid (from 1999-01-01; Lic Eng December 2000; PhD December 2002) |
| *Period* | 1999-01-01 – 2003-06-30 (– 2003-12-31) |
| *Chalmers budget (excluding university basic resources)* | Stage 2: KSEK 710<br>Stage 3: KSEK 1585<br>Stage 4: KSEK 385 |
| *Industrial interests in-kind budget (Banverket)* | Stage 2: KSEK 500<br>Stage 3: KSEK 300<br>Stage 4: KSEK 150 |

*Note: VB5 has had an additional funding of KSEK 250 for each one of the first four years from the Swedish Foundation for Strategic Research (SSF) through its National Graduate School in Scientific Computation (NGSSC).*

At places in Sweden where ground conditions are poor with deep layers of loose 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, the VB5 project has aimed at providing an understanding of which factors affect the vibration levels. It should then be possible to propose measures to reduce these levels.

Numerical models in space and time have been developed using adaptive finite element technology. By use of the Scaled Boundary Finite Element Method (SBFEM), reflections at the boundaries of the models have been avoided and the spatial extension of the models limited. A so-called multigrid technique has been developed. This technique enables computers with a relatively small storage capacity to handle large and detailed models reasonably quickly. The complexity (calculation time) then only increases linearly with the resolution (number of equations), a fact which can be regarded as a unique property. The technique has also proved to be applicable not only to linear problems but also to problems that include non-linear effects (at least material such effects). Simulations in two and three dimensions have been carried out. The in-field measurements at Ledsgård south of Gothenburg in the spring of 2000 have been evaluated and exploited. Parametric studies have shown that the



Example in project VB5 of three-dimensional simulation of wave propagation. The length of the model is 89 m. It is enclosed by a non-reflecting layer of scaled boundary finite elements. The train has ten bogies (twenty wheelsets). The two train speeds considered are 50 m/s (below the critical value) and 70 m/s (above the critical value). Snapshots are shown of the displacement field when the train has reached the same position in the two cases. The displacements have been magnified by the factor 200

## VB5. (cont'd)

speed of the train and the properties of the clay play a major role for the vibrations.

The research plan dated 2000-09-27 (for the continuation of the VB5 project) in the separate application to Banverket by Nils-Erik Wiberg was approved by the CHARMEC Board on 8 May 2001 and the project was again included in the Centre. See further the CHARMEC Triennial Report from Stage 2.

Torbjörn Ekevid successfully defended his doctoral dissertation (see below) in public on 18 December 2002. Professor Roger Owen of the Department of Civil Engineering at the University of Wales in Swansea, UK, served as the faculty-appointed external examiner.


Torbjörn Ekevid and Nils-Erik Wiberg: On parallel computations and wave propagation, *Proceedings Trends in Computational Structural Mechanics,* Lake Constance (Germany) May 2001, pp 447-459

Torbjörn Ekevid, Nils-Erik Wiberg and Martin X D Li: On wave propagation problems associated to high-speed trains, *Proceedings European Conference on Computational Mechanics (ECCM 01),* Cracow (Poland) June 2001, 20 pp on CD. Abstract on pp 930-931

Torbjörn Ekevid: Field measurements of ground vibrations at Ledsgård, Report 01:4, *Chalmers Structural Mechanics,* Gothenburg 2001, 30 pp

Martin X D Li, Alexander Smekal and Nils-Erik Wiberg: Finite element modelling of high-speed train induced track-ground vibrations, *Proceedings 8th International Congress on Sound and Vibration (ICSV8),* Hong Kong (China) July 2001, pp 2859-2866

Torbjörn Ekevid and Nils-Erik Wiberg: High-speed induced ground vibrations – an application of the scaled boundary finite element method, *Proceedings 14th Nordic Seminar on Computational Mechanics (NSCM-14),* Lund (Sweden) October 2001, pp 245-248

Torbjörn Ekevid, Martin X D Li and Nils-Erik Wiberg: Adaptive FEA of wave propagation induced by high-speed trains, *Computers & Structures,* vol 79, nos 29-30, 2001, pp 2693-2704

Torbjörn Ekevid and Nils-Erik Wiberg: A comparison of parallel implementation of explicit DG and central difference method, *Communications in Numerical Methods in Engineering,* vol 18, no 8, 2002, pp 585-597

Torbjörn Ekevid and Nils-Erik Wiberg: Wave propagation related to high-speed trains – a scaled boundary FE-approach for unbounded domains, *Computer Methods in Applied Mechanics and Engineering,* vol 191, no 36, 2002, pp 3947-3964

Torbjörn Ekevid and Nils-Erik Wiberg: Computational wave propagation by adaptive multigrid FE-technique (Keynote Lecture), *Proceedings 5th World Congress on Computational Mechanics (WCCM V),* Vienna (Austria) July 2002, 18 pp on CD, ISBN3-9501554-0-6, http://wccm.tuwien.ac.at. Abstract on p 609

Rikard Arnell and Karl-Gustaf Piper: Dynamic FE-analysis of train-induced vibrations – a parameter study, MSc Thesis 02:6, *Chalmers Structural Mechanics,* Gothenburg 2002, 73 pp

Torbjörn Ekevid: Computational solid wave propagation – numerical techniques and industrial applications, Doctoral Dissertation, *Chalmers Structural Mechanics,* Gothenburg December 2002, 148 pp (summary and five appended papers)

Per Kettil, Torbjörn Ekevid and Nils-Erik Wiberg: Towards fully mesh adaptive FE-simulations in 3D using multigrid solver, *Computers & Structures,* vol 81, nos 8-11, 2003, pp 735-746

Torbjörn Ekevid, Per Kettil and Nils-Erik Wiberg: Adaptive multigrid FE-technique for computational plasticity, *Proceedings 7th International Conference on Computational Plasticity (COMPLAS 2003),* Barcelona (Spain) April 2003, 14 pp on CD. Abstract on p 144

Martin X D Li, Torbjörn Ekevid and Nils-Erik Wiberg: An integrated vehicle-track-ground model for investigating the wheel/rail dynamic forces due to high axle loads, *Proceedings 6th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2003),* Gothenburg June 2003, vol II, pp 295-300

Torbjörn Ekevid and Nils-Erik Wiberg: Analysis of high-speed train related ground vibrations by a hybrid method, *Proceedings IABSE Symposium: Structures for High-Speed Railway Transportation,* Antwerp (Belgium) August 2003, 6 pp on CD. Abstract on pp 240-241

Håkan Lane, Torbjörn Ekevid and Nils-Erik Wiberg: Adaptive solid wave propagation – influences of boundary conditions in high-speed train applications, *Proceedings 1st International Conference on Adaptive Modeling and Simulation (ADMOS),* Gothenburg September – October 2003, pp 93-94 (abstract only)


Dr Torbjörn Ekevid (left) and Professor Nils-Erik Wiberg of project VB5

# 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

| | |
|---|---|
| *Project leader* | Dr Johan Jonsson,<br>Assistant Professor,<br>Structural Engineering/<br>Applied Structural Dynamics |
| *Advisers* | Professor Thomas Abrahamsson,<br>Solid Mechanics<br>(now Applied Mechanics) |
| | Professor Kent Gylltoft,<br>Structural Engineering/<br>Concrete Structures |
| *Period* | 2000-07-01 – 2001-12-31 |
| *Chalmers budget (excluding university basic resources)* | Stage 3: KSEK 1050 |
| *Industrial interests in-kind budget (Banverket)* | Stage 3: KSEK 300 |

*For photos of Thomas Abrahamsson and Kent Gylltoft, see pages 16 and 34*

The VB6 project was intended as a continuation of VB1 with efforts more oriented 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. The budget has been reduced accordingly. One result of VB6 is an analytic study of a model containing a moving load on a Timoshenko beam which rests on a horizontally layered half-space. The new project VB8 will, at least partially, replace VB6.

Dr Johan Jonsson of project VB6

Vincent Gillard: Modal analysis and numerical modelling of a concrete railway sleeper, MSc Thesis 01:6, *Chalmers Structural Engineering,* Gothenburg 2001, 130 pp

Johan Jonsson: Final report on part of the CHARMEC project VB6 "Soil-structure interaction – countermeasures against ground vibrations from railway traffic", *Chalmers/CHARMEC,* Gothenburg 2002, 18 pp

Roger Lundén and Joe Cohen-Cramp, site manager, at Austrak's sleeper plant (an Abetong Teknik licensee) in Rockhampton, Queensland (Australia) in June 2001

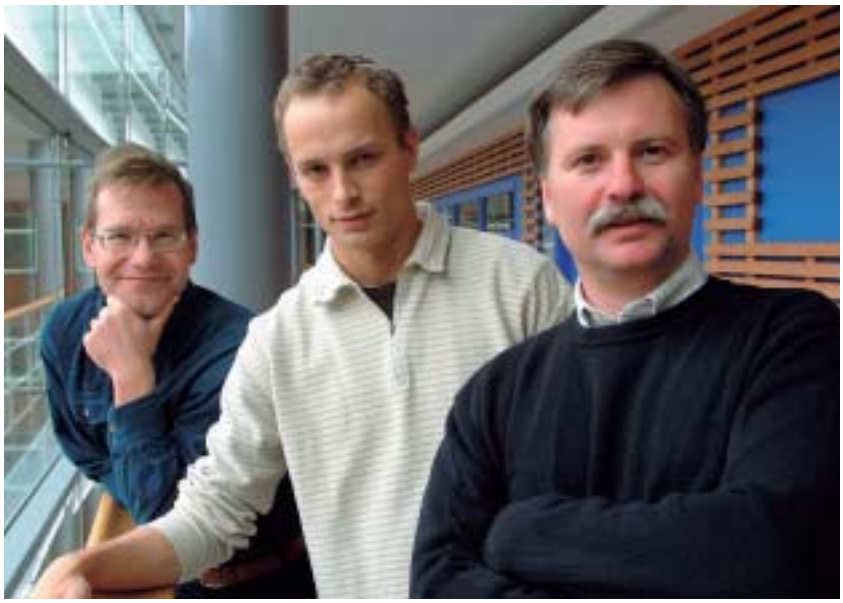
# VB7. VIBRATION TRANSMISSION IN RAILWAY VEHICLES

Vibrationsöverföring i järnvägsfordon
Übertragung von Vibrationen in Eisenbahnfahrzeugen
Transmission de vibrations dans les véhicules ferroviaires

| | |
|---|---|
| *Project leaders and supervisors* | Professor Thomas Abrahamsson, Applied Mechanics<br>Docent Tomas McKelvey, Signals and Systems |
| *Doctoral candidate* | Mr Joakim Gunnarsson, MSc (from 2001-11-01 to 2003-02-28)<br>Mr Per Kalling, MSc (from 2003-03-01) |
| *Period* | 2001-07-01 – 2003-06-30 (– 2008-02-29) |
| *Chalmers budget (excluding university basic resources)* | Stage 3: KSEK 1250<br>Stage 4: KSEK 2050 |
| *Industrial interests in-kind budget (Bombardier Transportation)* | Stage 3: KSEK 300<br>Stage 4: KSEK *200* |

Structure-borne vibrations and sound (SBV&S) are generated at the 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 will be on semi-physical modelling of the bogie suspension system (air cushions, dampers etc). Parameters will be identified from experimental results. Discussions have been conducted with Bombardier Transportation. One problem is that the bogie cannot be tested as a stand-alone non-loaded component since its properties are dramatically different in the mass-loaded (car weight) condition. A project plan dated 2001-02-12 was approved by the CHARMEC Board on 20 February 2001.



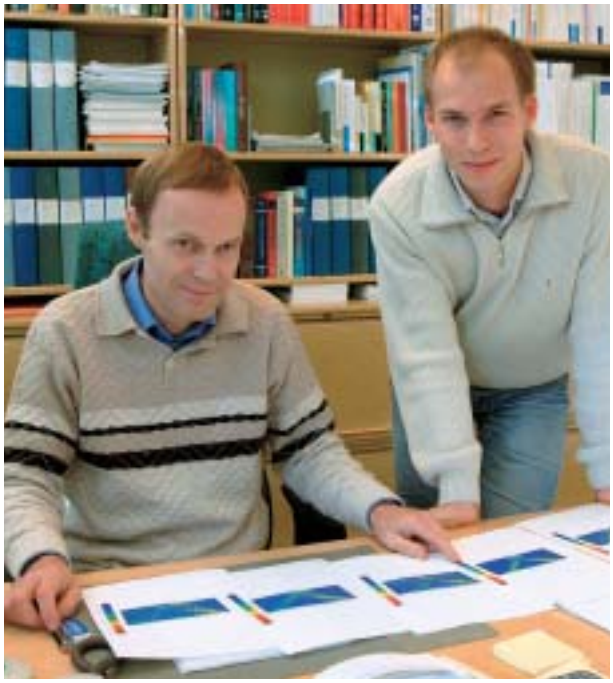
PhD student Per Kalling (centre) and his supervisors Docent Tomas McKelvey (left) and Professor Thomas Abrahamsson in project VB7

# VB8. GROUND VIBRATIONS FROM RAILWAYS

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

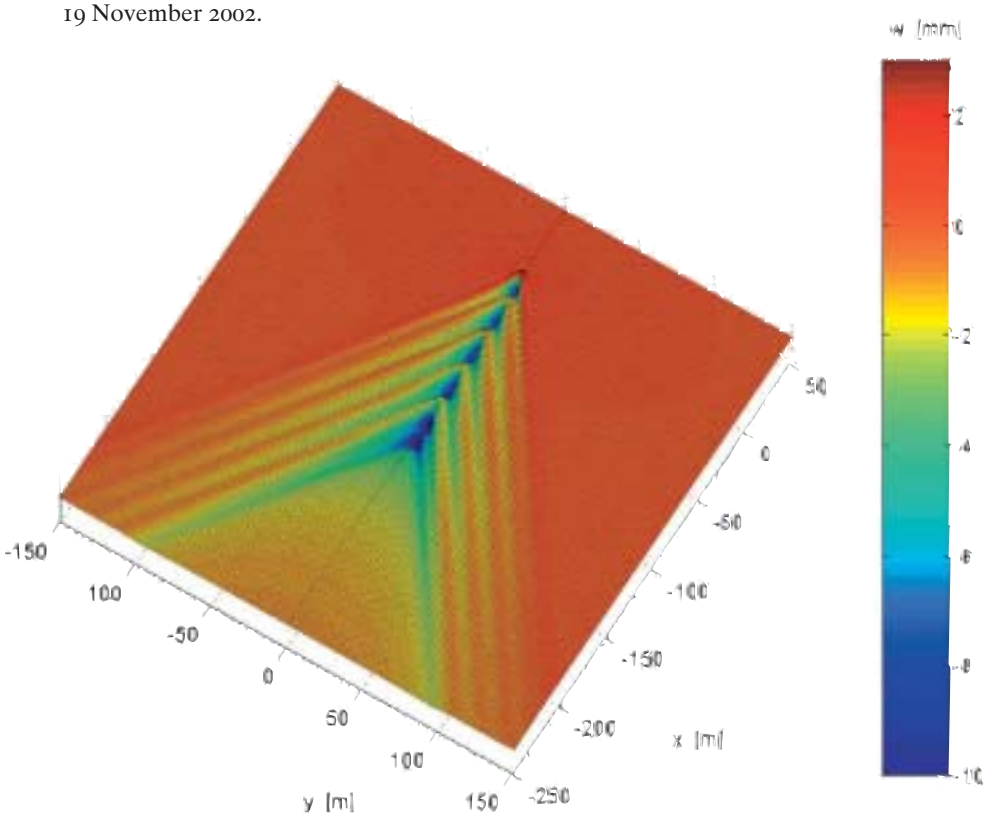
| | |
|---|---|
| *Project leader and supervisor* | Professor Anders Boström, Applied Mechanics |
| *Doctoral candidate* | Mr Anders Karlström, MSc (from 2002-12-09) |
| *Period* | 2002-12-01 – 2003-06-30 (– 2007-11-30) |
| *Chalmers budget (excluding university basic resources)* | Stage 3: kSEK 500<br>Stage 4: kSEK 2050 |
| *Industrial interests in-kind budget* | Stage 3: –<br>Stage 4: – |

In the VB8 project refined models of the ground vibrations caused by a train passage should be established. Simple analytical descriptions of sleepers and rails on an embankment resting on a layered ground have been planned. This means less flexibility compared to an FE model but will result in much faster computations and will also display the vibrational field at all positions. To increase the functionality, an FE model of the track and/or a building can later be linked to the analytical model. Countermeasures to combat ground vibrations induced by trains will be sought. A project plan dated 2002-11-15 was approved by the CHARMEC Board on 19 November 2002.



PhD student Anders Karlström (right) and his supervisor Professor Anders Boström in project VB8

Anders Karlström has attended graduate courses, in particular on wave propagation in solids, and he has started a literature survey. An analytical model has been developed and computer programming is under way.

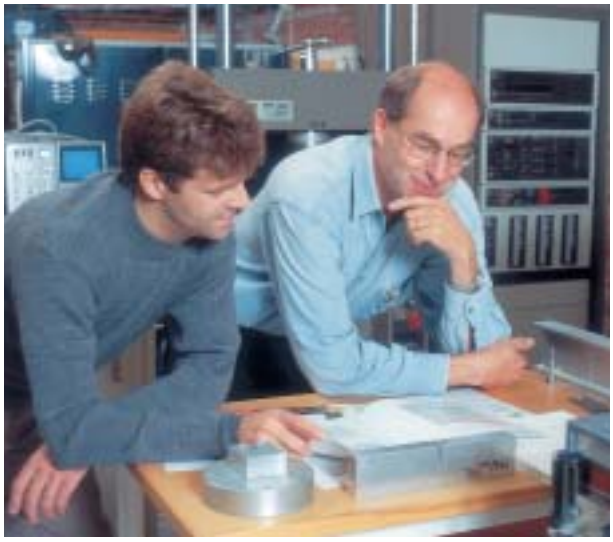



Example in project VB8 of calculated ground vibration as caused by an X2 train travelling at the constant speed 200 km/h. The embankment with the track (not visible in the picture) rests on a semi-infinite clay body, taken as homogeneous and linear viscoelastic, with shear wave speed 148 km/h (41 m/s). 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

# MU1. MECHANICAL PROPERTIES OF BALLAST

Ballastens mekaniska egenskaper
Mechanische Eigenschaften des Schotters
Propriétés mécaniques du ballast

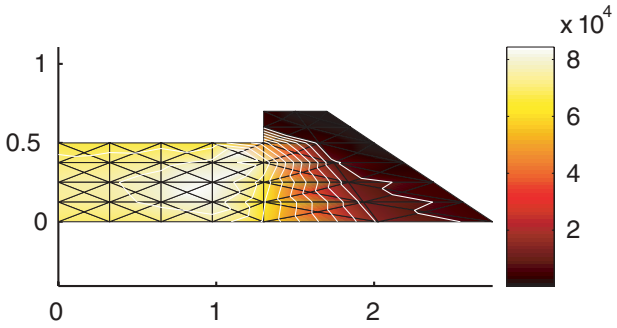
| | |
|---|---|
| *Project leader and supervisor* | Professor Kenneth Runesson, Solid Mechanics, (now Structural Engineering and Mechanics) |
| *Doctoral candidate* | Mr Lars Jacobsson (from 1996-04-01; Lic Eng January 1999) |
| *Period* | 1996-01-01 – 2001-06-30 |
| *Chalmers budget (excluding university basic resources)* | Stage 1: KSEK 1500<br>Stage 2: KSEK 2465<br>Stage 3: KSEK 650 |
| *Industrial interests in-kind budget* | Stage 1: KSEK 100 *(Abetong Teknik)*<br>Stage 2: KSEK 300 *(Banverket)* |



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

The mechanical properties of ballast determine its ability to distribute the load carried down to the ground in such a way as to prevent detrimental deformations of the track. The MU1 project aims at setting 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 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 long-term effects such as subsidence and conditioned elasticity properties after being rolled over many times. Calibrations have been performed against experiments with ballast in triaxial cells at the University of Colorado in Boulder (USA) and the University of Delft (the Netherlands). A cross-section of the track body (in plain strain) has been analysed.




Example in project MU1 of calculated deviatoric stress $q$ (effective stress according to von Mises, a measure of the maximum shear stress, Pa) in a ballast bed (in plain strain) under 22 tonne static axle load transmitted by rigid "sleepers" of width 0.60 m (equal to real sleeper spacing). The ballast bed is assumed to rest on a rigid ground. Maximum value of $q$ is 107 kPa

The work in the MU1 project is delayed. Lars Jacobsson has left Chalmers for employment from January 2002 at SP Swedish Testing and Research Institute in Borås. However, he has resumed work in May 2003 (being on leave from SP) to complete his doctoral dissertation. See further the CHARMEC Biennial and Triennial Reports from Stages 1 and 2 respectively.

Lars Jacobsson and Kenneth Runesson: Computational modeling of high cycle conditioning of coarse-sized granular materials, *Proceedings 2nd European Conference on Computational Mechanics (ECCM 01),* Cracow (Poland) June 2001, 10 pp on CD

Lars Jacobsson and Kenneth Runesson: Integration and calibration of a plasticity model for granular materials, *International Journal for Numerical and Analytical Methods in Geomechanics,* vol 26, no 3, 2002, pp 259-272

Lars Jacobsson and Kenneth Runesson: Computational modeling of high-cycle deformation of railway ballast, *Proceedings 5th World Congress on Computational Mechanics (WCCM V),* Vienna (Austria) July 2002, 12 pp (ISBN 3-9501554-0-6, http://wccm.tuwien.ac.at)

# 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

| | |
|---|---|
| *Project leader and supervisor* | Professor Birger Karlsson, Engineering Metals (now Materials Science and Engineering) |
| *Doctoral candidate* | Mr Johan Ahlström (from 1995-11-01; Lic Eng December 1998; PhD March 2001) |
| *Period* | 1995-07-01 – 2001-06-30 |
| *Chalmers budget (excluding university basic resources)* | Stage 1: KSEK 1400<br>Stage 2: KSEK 1800<br>Stage 3: KSEK 325 |
| *Industrial interests in-kind budget (Adtranz Wheelset/ Lucchini Sweden)* | Stage 1: KSEK 200<br>Stage 2: KSEK 300<br>Stage 3: KSEK 100 |

Dr Johan Ahlström (centre) with Professor Ian Hutchings (left) and Professor Birger Karlsson after Johan Ahlström's successful defence of his doctoral dissertation (examination in public) in March 2001

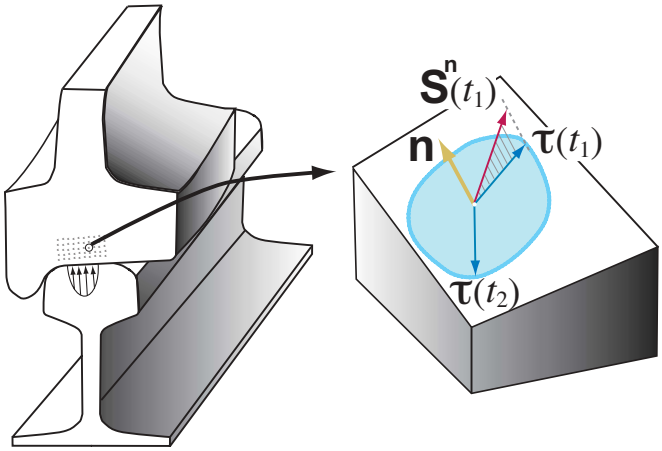
In the MU2 project, material structures have been sought that can better resist the mechanical and thermal loads on railway wheels. These loads originate from regular rolling contact and tread braking and irregular wheel sliding (wheel flats). As previously reported (see the CHARMEC Triennial Report from Stage 2), 36 castings with different levels of the micro-alloying elements and with different forging procedures and heat treatments up to the finished railway wheel have been produced in co-operation with Lucchini Sweden (formerly Adtranz Wheelset). Test pieces from the wheels with the new materials have now been extensively tested at Chalmers and Lucchini for fatigue behaviour (under strain control) and fracture toughness (Charpy V down to –40 °C). Candidates for improved material quality in the wheels have been found.

On 2 March 2001, Johan Ahlström successfully defended his doctoral dissertation (see below) in public. Professor Ian Hutchings of the Department of Materials Science and Metallurgy at the University of Cambridge, UK, served as the faculty-appointed external examiner. The MU2 project was concluded as planned by 30 June 2001. Since April 2001, Johan Ahlström has been employed as Assistant Professor at Chalmers Engineering Metals (now Chalmers Materials Science and Engineering). See further the CHARMEC Triennial Report from Stage 2.

Johan Ahlström: Thermal and mechanical behaviour of railway wheel steel, Doctoral Dissertation, *Chalmers Engineering Metals,* Gothenburg February 2001, 142 pp (summary and six appended papers)

Johan Ahlström and Birger Karlsson: Modified railway wheel steels – production and evaluation of mechanical properties with emphasis on low cycle fatigue behaviour, *Chalmers Engineering Metals,* Gothenburg 2001, 19 pp

Johan Ahlström and Birger Karlsson: Modelling of heat conduction and phase transformations during sliding of railway wheels, *Wear,* vol 253, nos 1-2, 2002, pp 291-300 (revised version of conference paper)



# 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's defence in public of his doctoral dissertation on 30 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 Technical University, Sweden. Professor Roger Lundén together with Professor Bengt Åkesson supervised the research.

A numerical model for the prediction of martensite formation under and around a wheel flat was developed. It was calibrated against the ca 240 wheel flats that had been created under controlled conditions in the field trials at Silinge (near Flen) 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. Better guidelines were proposed for the turning of wheels with wheel flats. See further the CHARMEC Biennial and Triennial Reports from Stages 1 and 2 respectively. Continued CHARMEC research in the area of project MU3 is reported below.

PhD student Johan Jergéus of project MU3. Photo taken 1997

Markus Wallentin, Hans Bjarnehed and Roger Lundén: Cracks around railway wheel flats exposed to rolling contact loads and residual stresses, *Proceedings 6th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2003),* Gothenburg June 2003, vol II, pp 385-396



# 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 defence in public of his doctoral dissertation on 7 April 2000 and his finalizing work up to 30 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 supervised the research. Since April 2000, Anders Ekberg has been employed as Assistant Professor at Chalmers Solid Mechanics (now Applied Mechanics) and has worked in close co-operation with Dr Elena Kabo.

← Example of shear stress path during one wheel revolution in a plane through a subsurface material point in the wheel rim as used in the Dang Van criterion. In WLIFE, 1600 such shear planes through each one of 32000 material points are used. Here, n = normal to plane, S = stress vector and $\tau$ = shear stress component of S at the two times $t_1$ and $t_2$

Drs Elena Kabo and Anders Ekberg in project MU4. Photo taken 2000. For a recently taken photo, see page 40

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 results of numerical simulations and on laboratory and in-field experiments. The Dang Van equivalent-stress criterion is applied in the calculation of fatigue damage in a multiaxial stress field. 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 (local defects) in the fatigue resistance. See further the CHARMEC Biennial and Triennial Reports from Stages 1 and 2 respectively. See also the MU9 project with continued research in the same area.

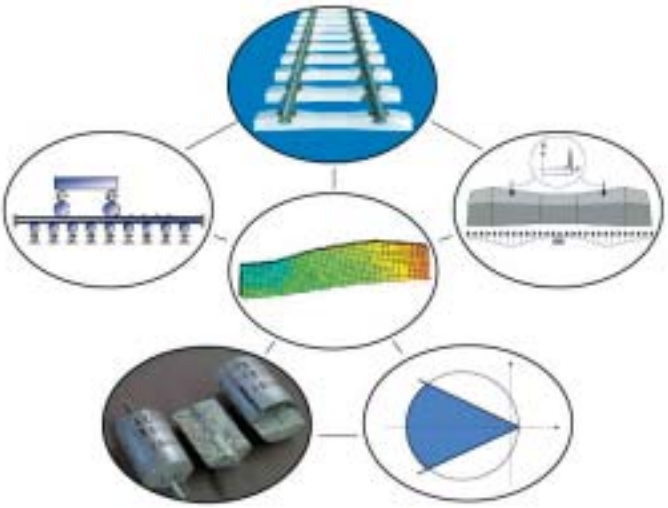
# MU5. MECHANICAL PROPERTIES OF CONCRETE SLEEPERS

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

| | |
|---|---|
| *Project leader and supervisor* | Professor Kent Gylltoft, Structural Engineering/ Concrete Structures |
| *Doctoral candidate* | Mr Rikard Gustavson (now Rikard Bolmsvik) (from 1997-12-01; Lic Eng May 2000; PhD November 2002) |
| *Period* | 1997-07-01 – 2002-12-30 |
| *Chalmers budget (excluding university basic resources)* | Stage 2: KSEK 2000<br>Stage 3: KSEK 1625 |
| *Industrial interests in-kind budget* | Stage 2: KSEK 600+100 *(Abetong Teknik+Banverket)*<br>Stage 3: KSEK 150 *(Abetong Teknik)* |

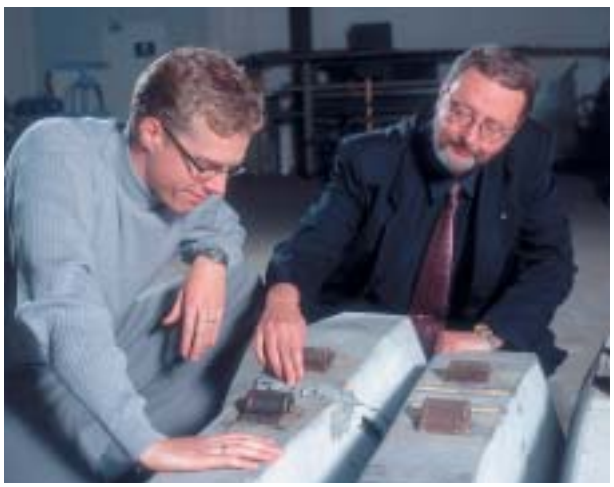
The MU5 project has aimed at developing methods for the analysis and dimensioning of concrete sleepers subjected to both static and dynamic loads. Rikard Gustavson successfully defended his doctoral dissertation (see below) in public on 7 November 2002. The faculty-appointed external examiner was Dr Jens Jacob Jensen of SINTEF Civil and Environmental Engineering in Trondheim, Norway. Since December 2002, Rikard Gustavson (Bolmsvik) has been employed by Abetong Teknik in Växjö.

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 of the strand surface or the concrete recipe that increases adhesion will thus largely improve the anchorage of the prestressing force during 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 submitted to increased loading.



A three-dimensional bonding model for the prestressed strands has been incorporated in the general computer program DIANA for concrete structures. Use of the FE 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 computer program DIFF (see under project TS1) was used to generate the operational loading on the sleeper.

An updated research plan dated 2000-09-13 was approved by the CHARMEC Board on 21 September 2000. Collaboration with Abetong Teknik has been close. See further the CHARMEC Triennial Report from Stage 2.



PhD student Rikard Gustavson (left) and his supervisor Professor Kent Gylltoft in project MU5. Photo taken 2000 in the laboratory of Chalmers Concrete Engineering

Rikard Gustavson and Kent Gylltoft: Static and dynamic response of concrete sleepers, *Nordic Concrete Research,* vol 2/00, 2000, pp 49-66

Rikard Gustavson: Steel-encased pull-through and push-in tests of indented three-wire strands, Report 01:2, *Chalmers Concrete Structures,* Gothenburg March 2001, 183 pp

Rikard Gustavson: Pull-through test of strands with various surface treatments and geometries, Report 01:6, *Chalmers Concrete Structures,* Gothenburg June 2001, 33 pp

Karin Lundgren and Rikard Gustavson: Examining bond by a combination of numerical modelling and tests, *Proceedings 18th Symposium on Nordic Concrete Research,* Elsinore (Denmark) June 2002, pp 63-65

## MU5. (cont'd)

Rikard Gustavson: Steel-encased pull-through tests of strands with various properties of the strand and the concrete, Report 02:1, *Chalmers Concrete Structures,* Gothenburg 2002, 205 pp

Karin Lundgren, Rikard Gustavson and Jonas Magnusson: Finite element modelling as a tool to understand the bond mechanisms, *Proceedings Bond in Concrete – from Research to Standards,* Budapest (Hungary) November 2002, pp 27-34

Rikard Gustavson: Bond response of three-wire strands: influence of strand and concrete, *ibidem,* pp 119-126

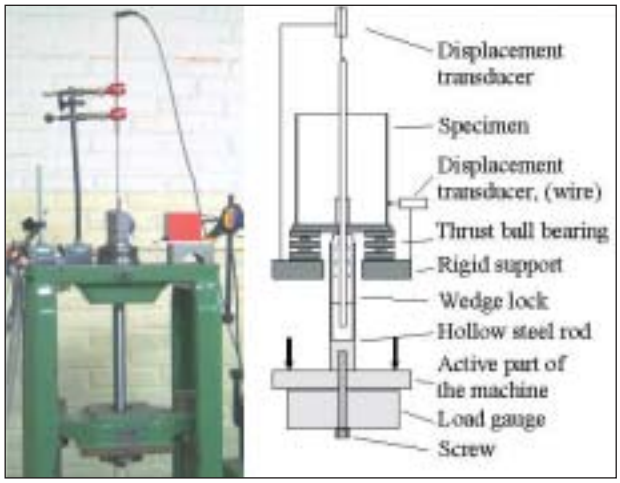
Rikard Gustavson: Structural behaviour of concrete railway sleepers, Doctoral Dissertation, *Chalmers Concrete Structures,* Gothenburg November 2002, 157 pp (summary and five appended papers)

Rikard Gustavson and Kent Gylltoft: Influence of cracked sleepers on the global track response: coupling of a linear track model and non-linerar FE analyses, *IMechE Journal of Rail and Rapid Transit,* vol 216, no F1, 2002, pp 41-51

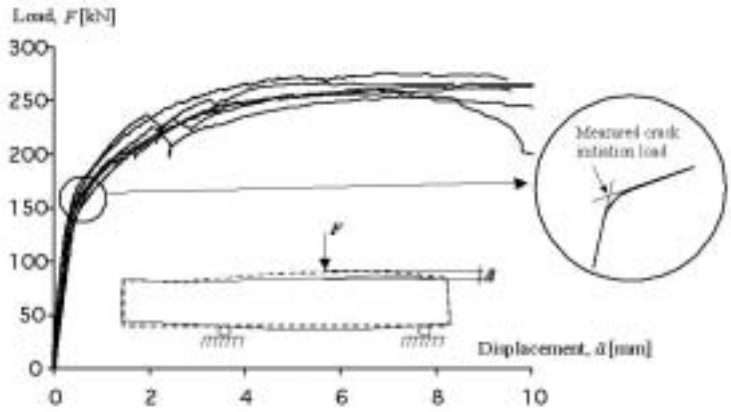
Rikard Gustavson: Bond behaviour of four types of strands in sleepers during release of prestress and loading, *Chalmers Concrete Structures,* Report 02:14, Gothenburg 2002, 152 pp (summary submitted for international publication)

Rikard Gustavson: Experimental studies of the bond response of three-wire strands and some influencing parameters, *RILEM Publications – Materials and Structures* (in press)

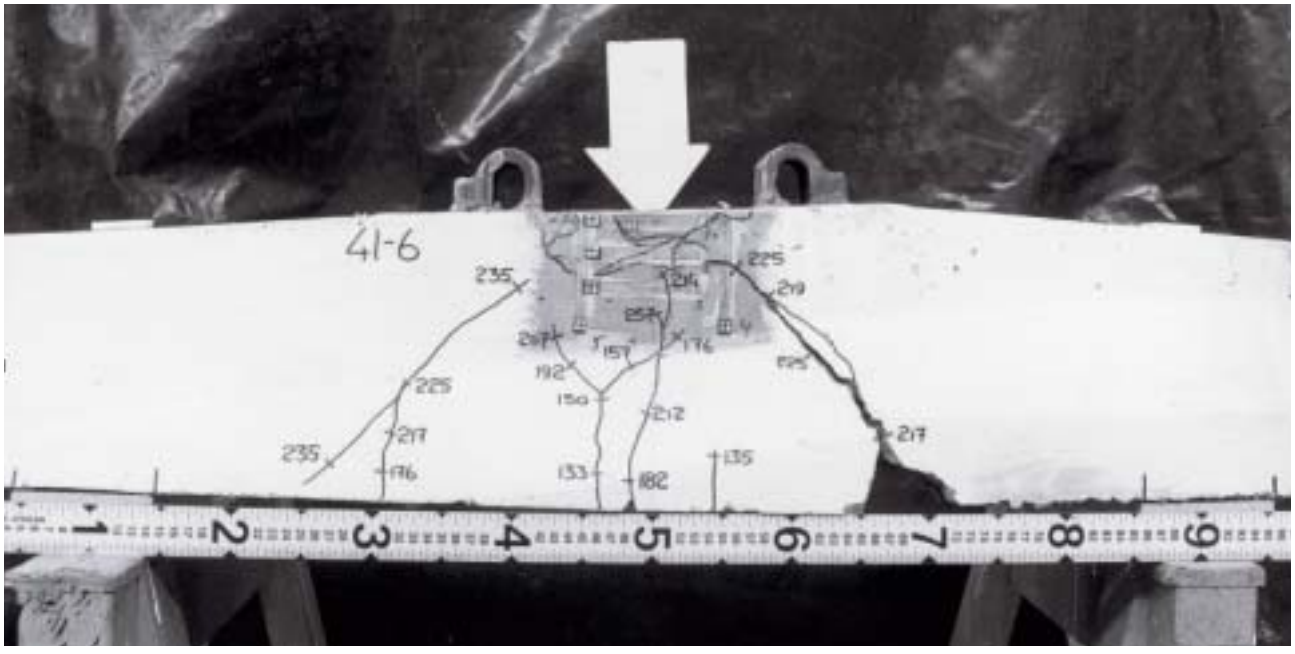
Rikard Gustavson and Karin Lundgren: Modelling of bond between three-wire strands and concrete (submitted to *Magazine of Concrete Research*)




Set-up of pull-through test (strand through concrete) in project MU5. Photo taken in the laboratory of Chalmers Concrete Structures




Load versus vertical displacement for six tested half-sleepers in project MU5. Method for determination of the crack initiation load




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

| | |
|---|---|
| *Project leader and supervisor* | Professor Lennart Josefson, Solid Mechanics (now Applied Mechanics) |
| *Doctoral candidate* | Mr Jonas Ringsberg (from 1998-01-01; Lic Eng before start of project; PhD September 2000) |
| *Period* | 1998-01-01 – 2000-09-30 |
| *Chalmers budget (excluding university basic resources)* | Stage 2: KSEK 1350<br>Stage 3: – |
| *Industrial interests in-kind budget (Inexa Profil)* | Stage 2: KSEK 450<br>Stage 3: – |

PhD student Jonas Ringsberg (left) and his supervisor Professor Lennart Josefson in project MU6. Photo taken 2000. For a recently taken photo, see page 38

The rolling contact between railway wheels and rails often results in fatigue damage in the railhead. The MU6 project has dealt with the cracks called head checks which, especially on curves, arise in a surface layer on the railhead. At high friction, successively 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.

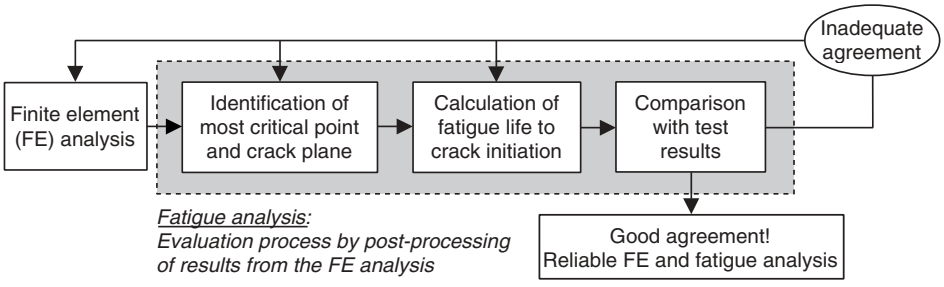
As previously mentioned, see the CHARMEC Triennial Report from Stage 2, Jonas Ringsberg successfully defended his doctoral dissertation on 15 September 2000 with Professor Roderick Smith of the Department of Mechanical Engineering at the University of Sheffield, UK, as the faculty-appointed external examiner. The title of the dissertation is "Rolling contact fatigue of railway rails with emphasis on crack initiation". Since September 2000, Jonas Ringsberg has been employed as Assistant Professor at Chalmers Solid Mechanics (now Applied Mechanics).


Jonas Ringsberg and Lennart Josefson: A method for prediction of fatigue crack initiation in railway rails, *Proceedings 6th International Conference on Biaxial/Multiaxial Fatigue and Fracture,* Lisbon (Portugal) June 2001, pp 477-484

Jonas Ringsberg and Lennart Josefson: Finite element analyses of rolling contact fatigue crack initiation in railheads, *IMechE Journal of Rail and Rapid Transit,* vol 215, no F4, 2001, pp 243-259

Jonas Ringsberg: Life prediction of rolling contact fatigue crack initiation, *International Journal of Fatigue,* vol 23, no 7, 2001, pp 575-586

Jonas Ringsberg and Torbjörn Lindbäck: Rolling contact fatigue analysis of rails including numerical simulations of the rail manufacturing process and repeated wheel-rail contact loads, *International Journal of Fatigue,* vol 25, no 6, 2003, pp 547-558


Strategy for fatigue life prediction of crack initiation in project MU6

# 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 Science and Engineering |
| *Doctoral candidate* | Mr Simon Niederhauser, Ingénieur diplomé, École Polytechnique Fédérale Lausanne (EPFL) (from 2000-04-17; Lic Eng February 2003) |
| *Period* | 2000-01-01 – 2003-06-30 (– 2005-03-31) |
| *Chalmers budget (excluding university basic resources)* | Stage 2: KSEK 700<br>Stage 3: KSEK 2050<br>Stage 4: KSEK 1300 |
| *Industrial interests in-kind budget* | Stage 2: KSEK 200+500+300 *(Adtranz Wheelset+Duroc +Inexa Profil)*<br>Stage 3: KSEK 500+200 *(Duroc+Lucchini Sweden)*<br>Stage 4: KSEK 400+200 *(Duroc Rail+Lucchini Sweden)* |

The MU7 project aims at studying the possibility of increasing the life and improving the functioning of railway wheels and rails onto which a surface layer (a coating) of powder has been melted with the aid of laser technology. Such a process allows for high-cost alloys being cladded on a cheaper substrate material. Different powders and process parameters can be used, whereby the microstructure and the friction and wear of the added layer can be varied. The objective is to find suitable combinations of surface layer and base material. The project is run in close collaboration with Duroc Rail.

Microscopy work and studies on tensile and fatigue behaviour have been performed on specimens from plates coated with two successive layers of Co-Cr by use of a multirun technique. The test plates were taken from a material volume in a new railway wheel (B82) close to the tread. Studies of the nucleation and growth of cracks preceding final fracture during the fatigue loading indicate that the heat-affected zone in the base material (consisting of highly tempered martensite) is more resistant to cracking than the base material and the coating. In the laboratory experiments, the coating itself behaved better than the substrate material alone. Further, it was found that the interface between the coating and the heat-affected zone did not constitute a weak zone.

Simon Niederhauser presented his licentiate thesis (see below) at a seminar on 28 February 2003. Apart from publications on the mechanical behaviour, a detailed report on the phase transformations taking place during coating and on the resulting microstructure is being compiled. The studies are continuing with new Fe-based coatings on the same base materials.

Simon Niederhauser and Birger Karlsson: Microstructure and mechanical properties of laser cladded steel plates, *Proceedings 10th International Conference on Fracture (ICF),* Honolulu HI (USA) December 2001, 6 pp on CD

Simon Niederhauser: Mechanical properties of laser cladded steel plates for railway applications, *Poster ASM/Juniormat,* Lausanne (Switzerland) September 2002

Simon Niederhauser: Properties of laser cladded railway steel, Licentiate Thesis, *Chalmers Materials Science and Engineering,* Gothenburg February 2003, 51 pp (summary and two appended papers)

Simon Niederhauser and Birger Karlsson: Comparison of fatigue behaviour of Co-Cr cladded steel plates for railway applications, *Proceedings 6th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2003),* Gothenburg June 2003, vol II, pp 567-572

Simon Niederhauser and Birger Karlsson: Fatigue behaviour of Co-Cr cladded steel plates for railway applications, *Wear* (accepted for publication). This is an extended version of the above conference paper

Simon Niederhauser and Birger Karlsson: Mechanical properties of laser cladded steel, 17 pp (submitted for international publication)

PhD students Simon Niederhauser (centre) in project MU7 and Niklas Köppen (left) in project MU16 with Dr Peter Sotkovszki of Chalmers Materials Science and Engineering

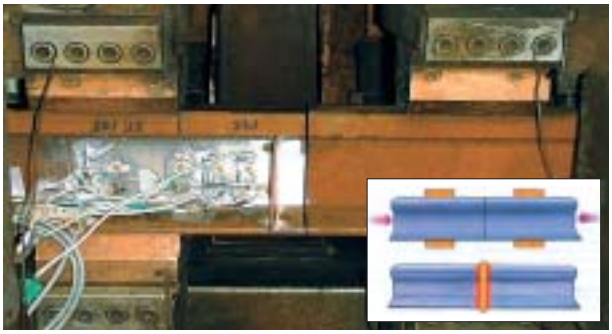
# MU8. BUTT-WELDING OF RAILS

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

| | |
|---|---|
| *Project leader and supervisor* | Professor Lennart Josefson, Applied Mechanics |
| *Assistant supervisor* | Dr Jonas Ringsberg, Assistant Professor, Applied Mechanics |
| *Doctoral candidate* | Mr Anders Skyttebol (previously Anders Salomonsson), (from 2001-03-01; Lic Eng before start of project) |
| *Period* | 2000-01-01 – 2003-06-30 (– 2004-03-31) |
| *Chalmers budget (excluding university basic resources)* | Stage 2: KSEK 450+100<br>Stage 3: KSEK 1850<br>Stage 4: – |
| *Industrial interests in-kind budget* | Stage 2: –<br>Stage 3: KSEK 200+150 *(Banverket+Inexa Profil)*<br>Stage 4: – |

Two different methods are used to butt-weld rails in Sweden: In stationary installations flash welding is applied to produce longer units while in the track thermite welding is used for the final joining. The welding process can affect the mechanical properties of the rails in two ways. First, residual stresses from the welding interact with stresses from the operational load on the track (global fatigue load and local contact load). This influences sensitivity to initiation of rolling contact fatigue cracks and thus the need for maintenance of the rails. Second, deformations in the weld joint affect the straightness of the rails and thus the running dynamics of the trains. The aim of the MU8 project is to quantify the impact of these two effects.

PhD student Anders Skyttebol (left) and his supervisor Professor Lennart Josefson in project MU8



Rendering of flash butt-welding and photo of measurement set-up at Sannahed in project MU8

A detailed three-dimensional numerical simulation of the electrical, thermal and mechanical fields during flash welding has been performed. Data for the thermal and electrical analyses were obtained both from the manufacturer of welding equipment, ESAB, and from a visit to Banverket's shop at Sannahed. Verifying experiments with the welding process were carried out at this facility in December 2001. The rail material used in the experiments was supplied by Inexa Profil before it closed down in October 2001. 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 speed 50 km/h) where information on contact forces is 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 growth of cracks from a size detectable by ultrasonics to a critical size has been determined. A numerical and experimental benchmark for the welding residual stress field is currently being run by a working group within IIW (International Institute of Welding) and the quality of the present FE-model will be checked in this test. The MU8 project has been delayed on account of Anders Skyttebol's leaving for service as officer in the reserves of the Swedish Army. A new proposed final date is 2004-03-01.

Lennart Josefson, Anders Skyttebol and Jonas Ringsberg: Numerical simulation of welding operations in connection to railway rails, Document IIW-X/XIII/XV-RSDP-75-02 presented at *IIW (International Institute of Welding) General Assembly,* Copenhagen (Denmark) June 2002, 2 pp

Anders Skyttebol and Lennart Josefson: Numerical simulation of flash butt-welding of railway rails, *Proceedings 7th International Seminar on Numerical Analysis of Weldability,* Graz-Seggau (Austria) September-October 2003, 21 pp (to appear)

Anders Skyttebol, Lennart Josefson and Jonas Ringsberg: Fatigue crack growth in a welded rail under the influence of residual stresses, *Engineering Fracture Mechanics* (special issue on fracture mechanics of railway components, to appear)

# MU9. ROLLING CONTACT FATIGUE OF RAILWAY WHEELS

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

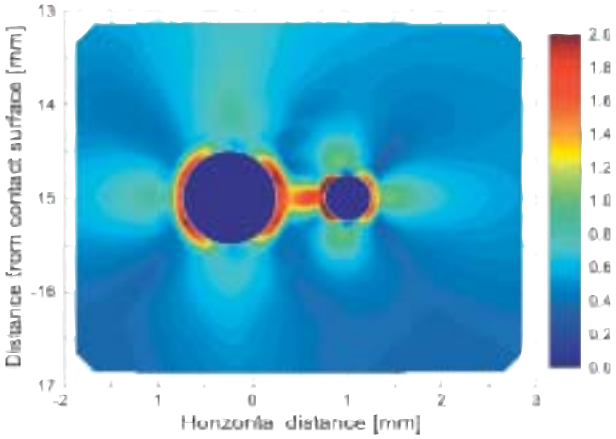
| | |
|---|---|
| *Project leaders* | Dr Anders Ekberg, Assistant Professor, and Dr Elena Kabo, Applied Mechanics |
| *Co-worker* | Professor Roger Lundén, Applied Mechanics |
| *Period* | 2000-07-01 – 2003-06-30 (– 2004-06-30) |
| *Chalmers budget (excluding university basic resources)* | Stage 3: KSEK 1350+200<br>Stage 4: KSEK 1000 |
| *Industrial interests in-kind budget* | Stage 3: KSEK 200+200 *(Bombardier Transportation +Lucchini Sweden)*<br>Stage 4: KSEK 100 *(Lucchini Sweden)* |

*For photos of Anders Ekberg, Elena Kabo and Roger Lundén, see pages 40 and 49*

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 is linked to such factors 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 both the mechanical properties of possible material defects and their form, size and physical location.

The overall aim of the MU9 project is to develop an "engineering" model of rolling contact fatigue 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. A project plan dated 2000-09-19 was approved by the CHARMEC Board on 21 September 2000. Several meetings have been held with Bombardier Transportation, Deutsche Bahn, Duroc Rail, MTAB, Spoornet and TrainTech Engineering. There has been coordination with the project 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 in 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 dynamic simulations of train-track interaction. Surface-initiated fatigue is assessed by use of shakedown theory. Subsurface-initiated fatigue is evaluated by use of a multiaxial fatigue criterion. Analytic expressions have been established for the fatigue impact, allowing very fast calculations. Parallel research is being carried out to evaluate the influence of single and clustered defects of varying size and location.




Example in project MU9 of calculated energy-type fatigue impact parameter (Jiang, MPa) in the vicinity of a defect cluster in a two-dimensional railway wheel model after five passages of rolling contact load 12 MN/m. Material pores of diameters 1.0 mm and 0.5 mm are separated by 0.5 mm. Distance from wheel tread is shown on the left

A reference group for the MU9 project has been established with members from Bombardier Transportation and TrainTech Engineering. Along with Jonas Ringsberg of project MU11, Anders Ekberg and Elena Kabo have worked as editors of the CM2003 proceedings, see page 63.

Anna Hansson: Contact mechanics – exploring some limitations of Hertzian theory, MSc Thesis EX 2001:3, *Chalmers Solid Mechanics,* Gothenburg 2001, 27 pp

Anders Ekberg, Elena Kabo and Hans Andersson: Predicting rolling contact fatigue of railway wheels, *Proceedings 13th International Wheelset Congress,* Rome (Italy) September 2001, 7 pp on CD

Elena Kabo: Material defects in rolling contact fatigue of railway wheels – influence of overloads and defect clusters, *International Journal of Fatigue,* vol 24, no 8, 2002, pp 887-894

Anders Ekberg and Roger Lundén: Rolling contact fatigue of railway wheels – towards validation of a predictive model, *Proceedings 8th International Fatigue Congress FATIGUE '2002,* Stockholm (Sweden) June 2002, vol 2, pp 843-850

Elena Kabo and Anders Ekberg: Fatigue initiation in railway wheels – a numerical study of the influence of defects, *Wear,* vol 253, nos 1-2, 2002, pp 26-34

→

# 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 Dr Anders Ekberg, Applied Mechanics |
| *Doctoral candidate* | Ms Eka Lansler, MSc (from 2002-02-01) |
| *Period* | 2002-02-01 – 2003-06-30 (– 2007-01-31) |
| *Chalmers budget (excluding university basic resources)* | Stage 3: KSEK 1100<br>Stage 4: KSEK 2050 |
| *Industrial interests in-kind budget (Lucchini Sweden)* | Stage 3: KSEK 400<br>Stage 4: KSEK 200 |

PhD student Eka Lansler (left) and her supervisors Professor Hans Andersson (right), Dr Elena Kabo and Dr Anders Ekberg in project MU10

Cracks in dynamically loaded metal structures are usually unavoidable. One design philosophy then is to ensure that the structure is inspected for cracks before any of them has reached a critical size. This requires predictive models of how rapidly a crack grows in the structure and under what conditions it will lead to complete structural failure. The aim of the MU10 project is to establish suitable models of crack growth and fracture for railway wheels. In particular, cracks initiated below the tread surface are to be studied keeping in mind that such cracks grow in a multiaxial and essentially compressive stress field with rotating principal directions. A project plan dated 2001-02-08 was approved by the CHARMEC Board on 20 February 2001.

Eka Lansler has attended graduate courses in preparation for her research work. A finite element model of a deep crack in a railway wheel has been developed. Numerical studies have been made of the relative displacement of the two faces of a subsurface crack during a load passage. A qualitative understanding has been obtained on how these displacements are influenced by parameters such as contact load magnitude and contact geometry. Methods for crack growth prediction based on mechanical quantities (stresses, strains, stress intensities, J-integrals etc) and measures of material resistance are currently being investigated.

The reference group of the project MU10 has members from Bombardier Transportation, Duroc Rail and Train-Tech Engineering.

Eka Lansler and Elena Kabo: Sub-surface crack face displacements in railway wheels, *Proceedings 6th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2003),* Gothenburg June 2003, vol II, pp 369-375

→ (FROM PREVIOUS PAGE)

Anders Ekberg, Elena Kabo and Hans Andersson: An engineering model for prediction of rolling contact fatigue of railway wheels, *Fatigue & Fracture of Engineering Materials & Structures,* vol 25, no 10, 2002, pp 899-909

Anders Ekberg and Elena Kabo: Rolling contact fatigue of railway wheels and rails – an overview, *Proceedings Rolling Contact Fatigue: Applications and Development,* Brescia (Italy) November 2002, pp 5-26

Elena Kabo and Anders Ekberg: The influence of defects in rolling contact fatigue, *ibidem,* pp 85-93

Elena Kabo and Anders Ekberg: Material defects in rolling contact fatigue of railway wheels – the influence of defect size, *Proceedings 6th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2003),* Gothenburg June 2003, vol I, pp 119-125

Anders Ekberg and Elena Kabo: Rolling contact fatigue of railway wheels and rails – an overview, *ibidem,* Appendix II, pp 11-24

Anders Ekberg, Elena Kabo and Jens Nielsen: Integrating rolling contact fatigue analysis with simulation of dynamic train-track interaction, *Proceedings 3rd International Conference "XXI Century Rolling Stock (ideas, requirements, projects)",* St Petersburg (Russia) July 2003, 11 pp

# 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* | Dr Jonas Ringsberg, Assistant Professor, and Professor Lennart Josefson, Applied Mechanics |
| *Doctoral candidate* | Mr Anders Bergkvist, MSc (from 2001-12-03) |
| *Period* | 2001-12-01 – 2003-06-30 (– 2006-11-30) |
| *Chalmers budget (excluding university basic resources)* | Stage 3: KSEK 1050<br>KSEK 250 *(voestalpine Schienen)*<br>Stage 4: KSEK 2050 |
| *Industrial interests in-kind budget* | Stage 3: KSEK 50 *(Inexa Profil)*<br>Stage 4: KSEK 600 *(voestalpine Bahnsysteme)* |

The aim of the MU11 project is to develop numerical models for 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. Examples of factors to be studied in the project and which influence the growth of a surface crack are (i) fluid/lubricant between the two crack faces (the fluid reduces the friction between these faces and a fluid enclosed between them can promote hydropressure-driven crack propagation), (ii) interaction between adjacent surface cracks, (iii) relationship between axle load and friction in the wheel-rail contact, (iv) speed and direction (spalling or rail fracture) of surface crack growth, and (v) varying traffic situations, e g trains moving in one or both directions on the track.

PhD student Anders Bergkvist (left) and his supervisor Dr Jonas Ringsberg in project MU11. For photo of Lennart Josefson, see page 38

A numerical method should be developed to predict when, how (direction) and how rapidly a predefined 0.3-0.5 mm long surface crack (head check) grows in a given traffic situation and a given external environment. The project has been partially financed by voestalpine Schienen GmbH during the period 1 January 2002 – 30 June 2003, see SP5 on page 59. A research plan dated 2001-04-23 was approved by the CHARMEC Board on 8 May 2001.

A parametrized two-dimensional finite element 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. The model has been used to investigate how the angle between the crack and the rolling contact surface and also the friction (between the crack faces and in the wheel-rail contact surface) influence the crack-generating force and the development of damage around the crack tip. Non-linear fracture mechanics have been adopted. Wear is included to account for a reduction of effective crack growth rate due to crack mouth truncation. A large number (approximately 500) of wheel passages (cycles) have been used in the FE calculations to investigate whether cyclic plasticity continues or if shakedown to an elastic state occurs. It has been found that the short surface-breaking cracks grow by shear. The highest crack growth rate is in the direction of the largest reversed shear strain range. See further the upper figure on page 40 in the CHARMEC Triennial Report from Stage 2.

Together with Anders Ekberg and Elena Kabo of project MU9, Jonas Ringsberg has worked as editor of the CM2003 proceedings, see page 63.

Jonas Ringsberg: Modelling the behaviour of short crack propagation in rails, *Proceedings 8th International Fatigue Congress FATIGUE 2002,* Stockholm (Sweden) June 2002, vol 5, pp 3015-3022

Jonas Ringsberg and Anders Bergkvist: A study on the behaviour of short surface-breaking cracks, *Proceedings Workshop on the Application of Fracture Mechanics to Railway Components,* GKSS, Geesthacht (Germany) April 2003, 2 pp (abstract only)

Jonas Ringsberg: Shear mode growth of short surface-breaking RCF cracks, *Proceedings 6th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2003),* Gothenburg June 2003, vol I, pp 29-38

Jonas Ringsberg and Anders Bergkvist: On propagation of short rolling contact fatigue cracks, *Fatigue & Fracture of Engineering Materials & Structures,* vol 26, no 10, 2003, pp 969-983

(SEE ALSO "SKETCH OF MECHANISMS" ON PAGE 45) ⟶

# MU12. CONTACT AND CRACK MECHANICS FOR RAILS

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

| | |
|---|---|
| *Project leader and supervisor* | Professor Peter Hansbo, Applied Mechanics |
| *Doctoral candidate* | Mr Per Heintz, MSc (from 2001-11-01; Lic Eng December 2003) |
| *Period* | 2001-11-01 – 2003-06-30 (– 2006-10-31) |
| *Chalmers budget (excluding university basic resources)* | Stage 3: KSEK 625<br>Stage 4: KSEK 1025 |
| *Industrial interests in-kind budget* | Stage 3: KSEK 50 *(Inexa Profil)*<br>Stage 4: KSEK 100 *(voestalpine Bahnsysteme)* |

PhD student Per Heintz (right) and his supervisor Professor Peter Hansbo in project MU12

Numerical (FE) techniques will be developed in the MU12 project to predict when and how a predefined crack in a rail will grow under given loading conditions. The usual node-to-segment contact algorithms will be avoided since they lack in accuracy and stability. Instead Lagrange multipliers (stabilized) will be employed to enforce zero penetration and a balance of forces at the interface. This promises to yield accurate contact forces, a factor of utmost importance in the current railway application. The overall aim of the project is (i) to develop new contact algorithms, (ii) accurately to describe contact forces, (iii) to develop FE techniques to handle crack propagation, and (iv) to establish stand-alone numerical libraries. A project plan dated 2001-01-23 was approved by the CHARMEC Board on 8 May 2001. The project is partially financed (50 %) by Chalmers Finite Element Center.

Numerical methods for goal-oriented adaptive mesh refinement in finite element models have been studied and implemented. This enables error control in arbitrary measurements, e g stresses, shear deformations etc. Adaptive finite element calculations have been carried out applying Eshelby mechanics (with material forces energy conjugated to the propagation of defects in the material) as the starting point. It has been shown that advanced adaptive methods provide a good way of ensuring the quality of the calculations. A special finite element code has been written in FORTRAN 90/95.

Two new FE methods for contact between two (or more) linearly elastic bodies with non-matching grids have been developed. They share the characteristic of being stable independently of the finite elements used, i e any finite element method can be employed. The methods have been successfully implemented in the in-house FORTRAN code which is now being extended to handle three-dimensional problems. This code will also be used in the MU11 project and extended to material models pertinent to rail cracking and spalling.

Per Heintz gained his degree of Licentiate of Engineering on 3 December 2003. At the licentiate seminar, the discussion was introduced by Docent Jonas Niklasson of Chalmers Applied Mechanics.


Per Heintz: Adaptive goal-oriented finite element computation of the energy release rate at crack growth, MSc Thesis EX2001:9, *Chalmers Applied Mechanics,* Gothenburg 2001, 58 pp

Per Heintz, Fredrik Larsson, Peter Hansbo and Kenneth Runesson: On error control and adaptivity for computing material forces in fracture mechanics (invited paper), *Proceedings 5th World Congress on Computational Mechanics (WCCM V),* Vienna (Austria) July 2002, ISBN 3-9501554-0-6, http://wccm.tuwien.ac.at, 10 pp

Per Heintz and Klas Samuelsson: On adaptive strategies and error control in fracture mechanics, *Computers & Structures* (to appear)

Per Heintz, Fredrik Larsson, Peter Hansbo and Kenneth Runesson: On adaptive strategies and error control for computing material forces in fracture mechanics, *International Journal of Numerical Methods in Engineering* (to appear)

Per Heintz and Peter Hansbo: A stabilized Lagrange multiplier method for contact phenomena, *Proceedings 6th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2003),* Gothenburg June 2003, vol I, pp 253-257

Per Heintz and Peter Hansbo: Consistent and inconsistent Lagrange multiplier methods for the finite element solution of unilateral contact problems using non-matching meshes, Presented at *7th US National Congress on Computational Mechanics,* Albuqerque NM, USA, July 2003, 1 p (abstract only)

Per Heintz and Peter Hansbo: Stabilized Lagrange multiplier methods for elastic contact (submitted to *Computer Methods in Applied Mechanics and Engineering*), 12 pp

Per Heintz: On computational contact and fracture mechanics, Licentiate Thesis, *Chalmers Applied Mechanics,* Gothenburg December 2003, 70 pp (summary and three appended papers)


Example in project MU12 of finite element analysis of frictionless linear elastic contact between a vertically loaded circular cylinder and a supporting rectangular block. Note the non-matching grids →

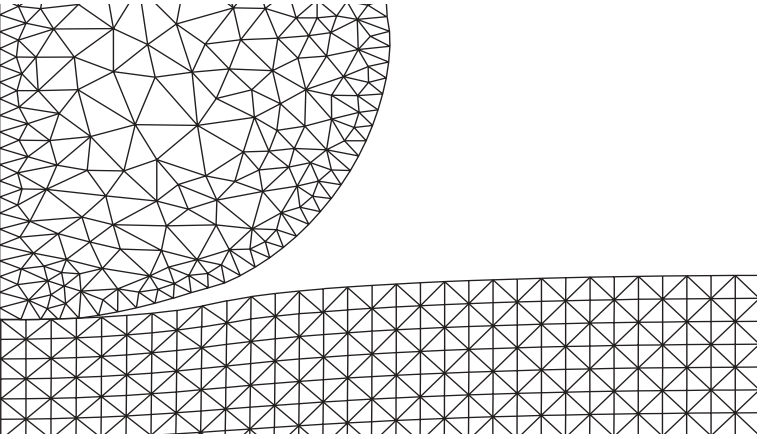
# MU13. WHEEL AND RAIL MATERIALS AT LOW TEMPERATURES

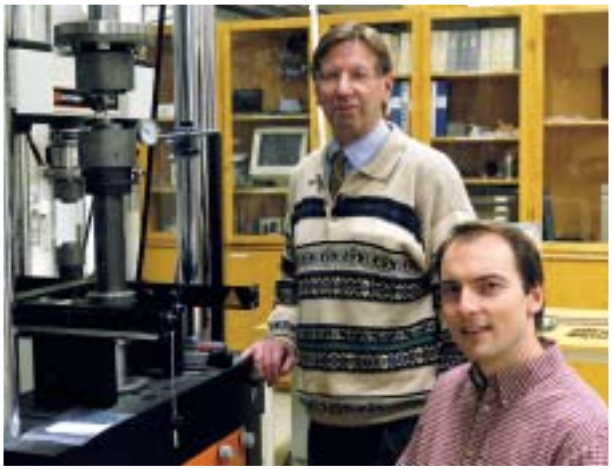
Hjul- och rälsmaterial vid låga temperaturer
Werkstoffe für Räder und Schienen bei niedrigen Temperaturen
Matériaux pour roues et rails aux basses températures

| | |
|---|---|
| *Project leaders* | Dr Johan Ahlström, Assistant Professor, and Professor Birger Karlsson, Materials Science and Engineering |
| *Period* | 2001-07-01 – 2003-06-30 (– 2005-06-30) |
| *Chalmers budget (excluding university basic resources)* | Stage 3: KSEK 1000<br>Stage 4: KSEK 1000 |
| *Industrial interests in-kind budget (Lucchini Sweden)* | Stage 3: KSEK 100<br>Stage 4: KSEK 200 |

Railway wheels and rails are steel components exposed to severe stresses. In general, steel has substantially inferior mechanical properties at low temperatures than at normal temperature. The MU13 project studies the influence of temperatures down to –40 °C on fatigue and fracture behaviour. In the previous project MU2, wheels of several different materials were manufactured in full scale. Specimens from these wheels were subject to tensile and impact testing at different temperatures as well as low-cycle fatigue testing at room temperature. In the present project, the low-cycle fatigue behaviour at low temperatures is examined for the most promising of these materials. A project plan dated 2001-04-17 was approved by the CHARMEC Board on 8 May 2001.

A low-temperature chamber has been installed on a servo-hydraulic fatigue testing machine in the laboratory. Tests have been run to identify important characteristics of this new equipment, such as speeds of cooling to, and heating from, the testing temperature.





Dr Johan Ahlström (right) and Professor Birger Karlsson in project MU13

Low-temperature chamber mounted on fatigue test rig in project MU13

The fatigue properties of the rail material UIC900A have been studied under both stress and strain controlled conditions. Stress-strain loop shapes, hardening/softening, fatigue life and the influence of positive mean stresses on ratchetting have been investigated for test bars taken from a commercial rail. The variation in microstructure and hardness over the cross section of the rail has been analysed. As regards the low-cycle fatigue behaviour of the pearlitic 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. When comparing the strain and stress controlled tests, the fatigue life was found to be very similar in the two cases provided that the stress and strain levels at saturation are selected correspondingly. Further, the strain rate has to be taken into account; it varies through the cycle during stress-controlled testing while it is constant during strain-controlled testing.

The work in the present project is co-ordinated with that in project MU16.

Johan Ahlström and Birger Karlsson: Fatigue behaviour of rail steel – a comparison between strain and stress controlled loading, *Proceedings 6th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems,* Gothenburg June 2003, vol II, pp 541-546

# MU14. DAMAGE IN TRACK SWITCHES

Skador i spårväxlar
Schäden an Weichen
Détérioration des aiguilles

| | |
|---|---|
| *Project leaders and supervisors* | Dr Magnus Ekh, Assistant Professor, and Professor Kenneth Runesson, Applied Mechanics |
| *Doctoral candidate* | Mr Göran Johansson, MSc (from 2002-08-01) |
| *Period* | 2002-08-01 – 2003-06-30 (– 2007-07-31) |
| *Chalmers budget (excluding university basic resources)* | Stage 3: KSEK 500<br>KSEK 150+150<br>*(VAE+voestalpine Schienen)*<br>Stage 4: KSEK 2150+100 |
| *Industrial interests in-kind budget* | Stage 3: –<br>Stage 4: KSEK 300+100+400<br>*(Banverket+SL Infrateknik +voestalpine Bahnsysteme)* |

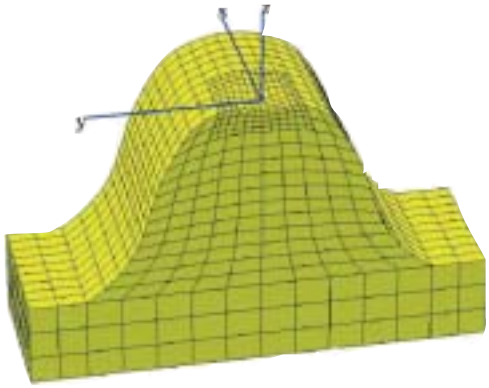
The Swedish railway network contains approximately ten thousand track switches (turnouts). Defects registered during track inspections by Banverket are very often related to these switches. Similar tendencies are reported outside Sweden by other railway administrations. The MU14 project aims at providing 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. Mathematical modelling and simulation of large deformations and damage in switch components due to cyclic loading will be carried out. The project consists of the following tasks: (i) formulation and calibration of a material model for steel subject to cyclic loading and large deformations, (ii) formulation and calibration of a model for damage development at large deformations, and (iii) numerical simulation of damage development to determine safe inspection intervals. Experiments will be performed in order to calibrate and validate the models. The project was initiated by Banverket and has been partially financed by VAE AG and voestalpine Schienen GmbH, see SP4 and SP5 on page 59. A project plan dated 2002-02-21 was approved by the CHARMEC Board on 6 March 2002.

A hyper-elastoplastic material model has been developed. A preliminary calibration of the model against uniaxial test data for UIC900A rail steel has been carried out by Johan Ahlström in project MU13. The model has been further refined to mimic realistic multiaxial ratchetting behaviour and has been implemented in a finite element program written in FORTRAN 90. An oral presentation of research results was given at the 10th International Symposium on Plasticity and Its Current Applications on 7-11 July 2003 in Québec City, Canada.

The projects TS7 and MU14 have a joint reference group, see under project TS7.

PhD student Göran Johansson (centre) and his supervisors Dr Magnus Ekh (right) and Professor Kenneth Runesson in project MU14

Göran Johansson, Magnus Ekh and Kenneth Runesson: Computational modelling of inelastic large ratchetting strains (submitted to *International Journal of Plasticity*), 29 pp



Crossing nose and its finite element modelling in project MU14 (see drawing of switch on page 21)

# 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, Materials Science and Engineering |
| *Co-worker* | Dr Johan Ahlström, Assistant Professor, Materials Science and Engineering |
| *Period* | 2001-07-01 – 2003-06-30 (– 2003-09-30) |
| *Chalmers budget (excluding university basic resources)* | Stage 3: KSEK 600<br>Stage 4: – |
| *Industrial interests in-kind budget* | Stage 3: KSEK 150 *(Duroc)*<br>Stage 4: – |

*For photo of Birger Karlsson and Johan Ahlström, see page 43*

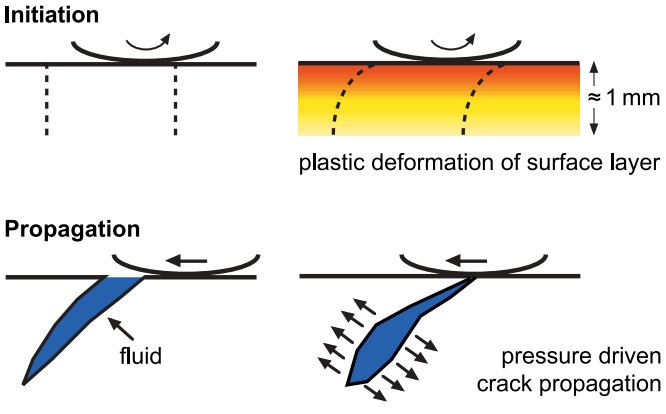
Railway wheels and rails are steel components which interact via direct contact. The tribological properties in the contact patch can be improved by replacing one of the materials. One way of doing this is to coat either the wheel tread or exposed parts of the railhead with Co-Cr using a laser based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

Calculations with an axisymmetric model have been applied to the successive passes in the two layers that are used in the present coating process. Qualitatively good descriptions of the heating/cooling cycles have been attained and temperature-time relations have been established at different depths of the heat-affected zone during the coating steps. A critical step in the laser coating technique has been identified, namely the creation and later annealing of martensite in the heat-affected zone. The annealing characteristics have earlier been investigated and described in terms of isothermal annealing during time periods down to 10 s. Methods for annealing during much shorter times by use of a special laser-pulse technique have now been developed in collaboration with a research group in Austria.

Alexandre Gorski: Tempering of rail and railway-wheel steels, MSc Thesis EX16/2002, *Chalmers Materials Science and Engineering,* Gothenburg 2002, 42 pp + Appendix 13 pp

Johan Ahlström, Birger Karlsson and Simon Niederhauser: Modelling of laser cladding of medium carbon steel – a first approach, *Proceedings 2nd International Conference on Thermal Process Modelling and Computer Simulation,* Nancy (France) March-April 2003, 8 pp. This report is under review for inclusion in *Journal de Physique IV*

(CONT'D FROM MU11 ON PAGE 41)




Sketch of mechanisms behind plasticity-induced crack initiation and fluid-assisted crack propagation in project MU11

# 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 Science and Engineering |
| *Doctoral candidate* | Mr Niklas Köppen, MSc (from 2003-10-01) |
| *Period* | 2003-03-01 – 2003-06-30 (– 2008-09-01) |
| *Chalmers budget (excluding university basic resources)* | Stage 3: KSEK 50<br>Stage 4: KSEK 2150 |
| *Industrial interests in-kind budget* | Stage 3: –<br>Stage 4: KSEK 100+700<br>*(Bombardier Transportation +Lucchini Sweden)* |

*For photos of Johan Ahlström, Birger Karlsson and Niklas Köppen, see pages 37 and 43*

Higher demands on service life together with higher nominal loadings argue for better wheel and rail materials. Cleaner steels, systematic ultrasonic testing of manufactured components and better control of brake systems in wagons should all decrease the likelihood of accidents in railway traffic. In practice, however, all components suffer now and then from unexpected high loadings and internal or external defects etc. This calls for more damage-tolerant base materials. The aim of the MU16 project is to study and develop alternative materials/microstructures with respect to fatigue strength under varying conditions, the most important being low temperatures when embrittlement may take place. A close collaboration with Lucchini in Italy and Sweden will be pursued. A project plan dated 2002-08-26 was approved by the CHARMEC Board on 19 November 2002.

New wheel materials provided by Lucchini from Lovere (Italy) will be investigated regarding tensile and fatigue behaviour at room temperature and at temperatures down to –60 °C. Microstructural effects and fractographic appearance will be studied.



# 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 Machine and Vehicle Systems) |
| *Doctoral candidate* | Mr Daniel Thuresson (from 1998-12-01; Lic Eng May 2001) |
| *Period* | 1998-12-01 – 2003-06-30 (– 2006-06-30) |
| *Chalmers budget (excluding university basic resources)* | Stage 2: KSEK 1400<br>Stage 3: KSEK 1300<br>Stage 4: KSEK 500 |
| *Industrial interests in-kind budget* | Stage 2: KSEK 400+100<br>*(Cardo Rail+SJ Teknik)*<br>Stage 3: KSEK 250<br>*(SAB WABCO)*<br>Stage 4: KSEK 180+200<br>*(Green Cargo+SAB WABCO)* |

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

Wheels and brakes share a considerable burden of the maintenance costs for freight wagons. Greater speeds and increased axle loads have placed higher demands on

## SD1. (cont'd)

the brakes. Of special importance are the thermal and mechanical properties (fatigue, wear, friction etc) in 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. The SD1 project aims at describing the interaction between block and wheel by use of simple (but physically correct) models of various phenomena. The analysis of the system should result in the identification of critical parameters. As earlier reported, see the CHARMEC Triennial Report from Stage 2, Göran Gerbert formally left his chair at Chalmers in December 2000, but continues informally as supervisor for Daniel Thuresson.

A thermomechanical model has been established and implemented in which the brake block is elastic while the wheel is regarded as rigid but thermally conductive. The model can handle wear and also temperature-dependent coefficients etc. Beneficial combinations of design parameters have been sought. Thermoelastic instability including wear has been studied by means of analytical solutions. Control of the brake system can prove to be a problem in the form of locking wheels when empty wagons are mixed with fully laden ones in a trainset. It is planned that different configurations of wagons and different combinations of brake blocks will be investigated in order to devise methods to improve the overall braking.

Daniel Thuresson presented his licentiate thesis (see below) on 16 May 2001 with Dr Johan Hulthén of Volvo Trucks introducing the discussion. In June 2001, Daniel Thuresson met with a serious accident and has since then been on sick leave alternating with working half-time. The project SD1 is therefore delayed relative to the research plan dated 1998-03-09.

Daniel Thuresson: Thermo-mechanical behaviour of sliding contact, Licentiate Thesis, *Chalmers Machine and Vehicle Design,* Gothenburg May 2001, 77 pp (summary and two appended papers)

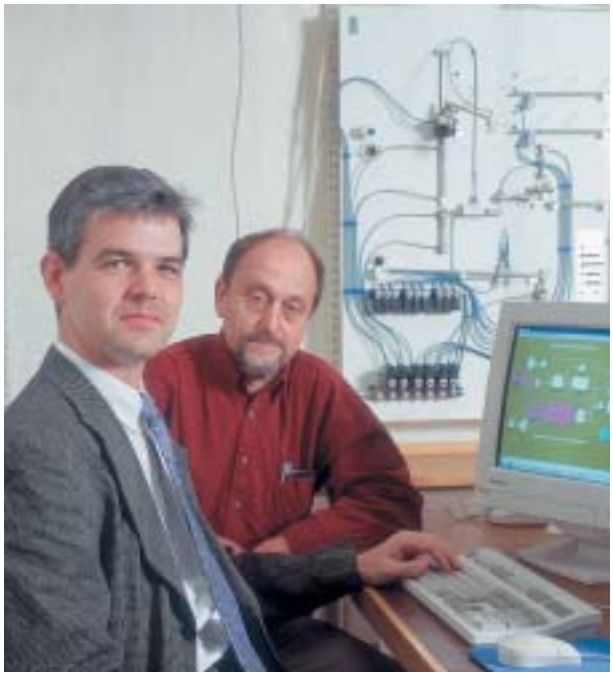
Daniel Thuresson: Influence of material properties on sliding contact braking applications, *Chalmers Machine and Vehicle Design,* Gothenburg 2001, 17 pp (submitted for international publication)



## 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) has been studied theoretically, numerically and experimentally. Scale-model experiments were performed at Chalmers and full-scale experiments with brake lines (including hoses, accumulators etc) up to 1200 m in length at SAB WABCO's brake system simulator in Piossasco, Italy, as well as on stationary and rolling freight trains in Sweden. Sensors, actuators and softwares 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).



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

# 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) |
| *Period* | 1998-07-01 – 2003-06-30 (– 2004-06-30) |
| *Chalmers budget (excluding university basic resources)* | Stage 2: KSEK 300+100<br>Stage 3: KSEK 1650<br>Stage 4: – |
| *Industrial interests in-kind budget* | Stage 2: KSEK 250+200 *(Cardo Rail+SJ)*<br>Stage 3: KSEK 250+50 *(SAB WABCO+TrainTech Engineering)*<br>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 as regards 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 the SD3 project is how to achieve a satisfactory level of safety with today's commercially available technology.

Håkan Edler formally left his post at Chalmers in September 2000 but has continued to contribute as project leader. Jan Torin left his chair in May 2001 but continues as supervisor. The project plan dated 1999-02-09 was approved by the CHARMEC Board on 11 February 1999. As of 1 January 2001, the project SD3 was transferred to Chalmers Lindholmen University College where Roger Johansson is employed.

A fault-tolerant control system architecture has been devised and transformed into a brake system specification which has been tested and verified using the concepts "inherent redundancy" and "programmable fail-safe behaviour". The brake system specification is to be implemented using VHDL (VHSIC Hardware Description Language with VHSIC standing for Very High Speed Integrated Circuit) and will be suitable for synthesis in FPGA (Field Programmable Gate Array) to be hosted by a test-bench.

The project SD3 has a reference group with members from Green Cargo, SAB WABCO and SP and also Halmstad University.

PhD student Roger Johansson (centre) and his project leader Mr Håkan Edler (left) and supervisor Professor Jan Torin in project SD3

Roger Johansson: Dependability characteristics and safety criteria for an embedded distributed brake control system in railway freight trains, Report no 8, *Chalmers Lindholmen University College (Electrical and Computer Engineering),* Gothenburg 2001, 16 pp

Roger Johansson and Jan Torin: On calculating guaranteed message response times on the SAE J1939 bus, Report no 10, *ibidem,* Gothenburg 2002, 9 pp

Roger Johansson, Per Johannessen, Kristina Forsberg, Håkan Sivencrona and Jan Torin: On communication requirements for control-by-wire applications, *Proceedings 21st International System Safety Conference 2003 (ISSC21),* Ottawa (Canada) August 2003, pp 1123-1132

# SD4. CONTROL OF BLOCK BRAKING

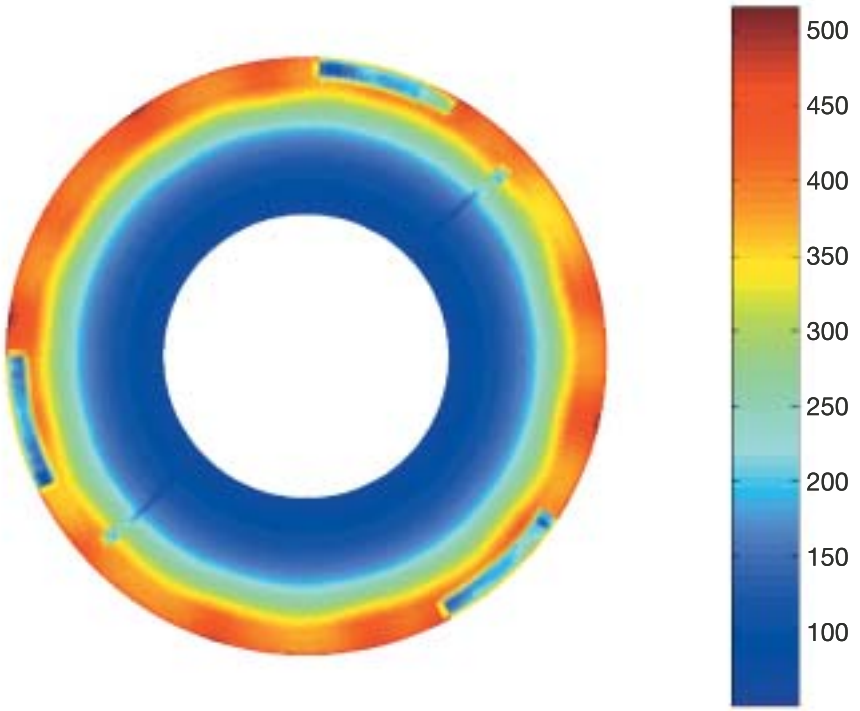
Reglering av blockbromsning
Steuerung von Klotzbremsen
Contrôle du freinage à sabot

| | |
|---|---|
| *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) |
| *Period* | 2001-03-01 – 2003-06-30 (– 2005-06-30) |
| *Chalmers budget (excluding university basic resources)* | Stage 3: KSEK 1700<br>Stage 4: KSEK 1300+200 |
| *Industrial interests in-kind budget* | Stage 3: KSEK 600+400+50 *(Lucchini Sweden+SAB WABCO +TrainTech Engineering)*<br>Stage 4: KSEK 300+400+700+100 *(Green Cargo+Lucchini Sweden +SAB WABCO+TrainTech Engineering)* |

PhD student Tore Vernersson (left) and his supervisor Professor Roger Lundén in project SD4. A brake block on part of a wheel rim is studied

The most common braking system on freight wagons in Europe is tread braking. This is achieved by one or more brake blocks being pressed against the tread of the wheel at the same time as the wheel rolls on the rail. The brake blocks may be made of cast iron, composite material or sinter material. The block-braking system is relatively cheap and reliable and makes for good adhesion between wheel and rail due to the roughening of the wheel tread. However, the generated frictional heat 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. The SD4 project aims at improved knowledge and control of the heat distribution between block and wheel. A project plan dated 2001-02-16 was approved by the CHARMEC Board on 20 February 2001.

The work in the SD4 project is focused on the behaviour of the wheel in the block-braking system. Both thermal and mechanical phenomena are being studied




Temperature (in °C) on field side of rotating and tread braked SURA 25 wheel as measured in project SD4. The wheel is turned to its limiting diameter. Drag braking with power 50 kW has been applied for 40 minutes in the test rig at Surahammar. Except for the three portions along the rim (showing the rim thickness in blue), the wheel side was painted black to facilitate the measurement by use of a thermocamera with scanning frequency 2500 Hz. The registered maximum temperature is 490 °C. The central part of the wheel side is hidden behind a bearing

## SD4. (cont'd)

for different brake histories using both computer simulations and experimental data. Numerical and experimental results obtained in earlier and ongoing work on tread brakes in the projects VB2, SD1 and EU1 have been utilized. Mr Hans Johansson, Technician of Chalmers Applied Mechanics, contributed to the experimental work (see page 52 for photo).

It has been found that the heat generated at the contact patch between wheel and rail due to slip is negligible. Planning of a new full-scale test series has started. In cooperation with the EU8 project, new three-dimensional numerical models of wheels, blocks and rails have been developed and results from simulations using these models are being analysed.

There is a delay in project SD4 since Tore Vernersson has also been involved in the projects VB3, VB4 and EU8, work which has been time-consuming but which has led to synergetic effects. The period of the SD4 project as originally planned has been extended by one year. An extensive literature survey has been made and reported.

The project SD4 has a reference group with members from SAB WABCO and TrainTech Engineering.

Tore Vernersson: Control of railway block braking – thermo-mechanical performance of wheels: a literature survey, Research Report 2002:6, *Chalmers Applied Mechanics,* Gothenburg 2002, 71 pp

Jens Nielsen, Roger Lundén, Anders Johansson and Tore Vernersson: Train-track interaction and mechanisms of irregular wear on wheel and rail surfaces, *Vehicle System Dynamics,* vol 40, nos 1-3, 2003, pp 3-54. Presented as an invited Keynote Lecture at the *18th International Symposium Dynamics of Vehicles on Roads and Tracks* in Atsugi, Kanagawa (Japan) August 2003 (this reference is also given under project TS5)

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 kgm², 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 |

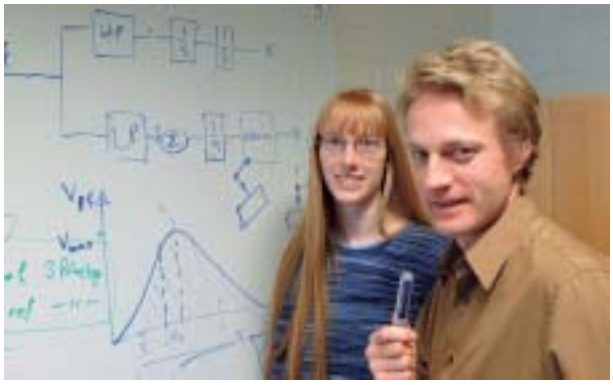
**Design for two extreme stop braking cases**

| $2m$ | $v_0$ | $s_{sign}$ | $s_b$ | $t_b$ | $r$ | $Q_0$ | $E$ | $D$ | $n$ | $M$ |
|---|---|---|---|---|---|---|---|---|---|---|
| tonnes | km/h | m | m | s | m/s² | 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

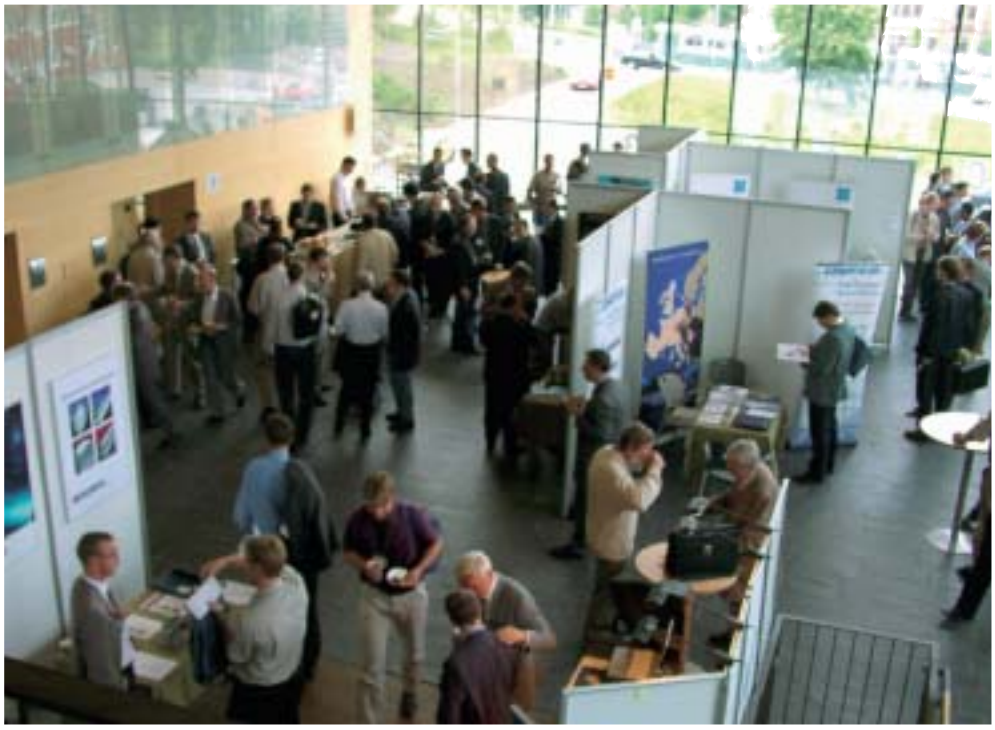
| | |
|---|---|
| *Project leader and supervisor* | Professor Jonas Sjöberg, Machine and Vehicle Systems |
| *Doctoral candidate* | Mr Daniel Atieh, MSc (from 2001-11-01 to 2003-01-31) |
| | Ms Jessica Fagerlund, MSc (from 2003-03-24) |
| *Period* | 2001-11-01 – 2003-06-30 (– 2008-02-29) |
| *Chalmers budget (excluding university basic resources)* | Stage 3: KSEK 1175<br>Stage 4: KSEK 1600 |
| *Industrial interests in-kind budget (Bombardier Transportation)* | Stage 3: KSEK 300<br>Stage 4: KSEK 200 |



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

The dynamic variations of 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 the 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 project plan dated 2001-02-12 was approved by the CHARMEC Board on 20 February 2001. The project is being run by the mechatronics group within the Department of Machine and Vehicle Systems.

A literature survey has been made and simple simulations have been performed. The new doctoral candidate Jessica Fagerlund has taken graduate courses. Discussions have been had with Bombardier Transportation. One idea is further to develop Bombardier's Electrical Hold-Off Device (EHOD). The SD5 project is delayed because of the unforeseen exchange of doctoral student.



Exhibition in the foyer of the Student Union Building on the Chalmers campus during the conference CM2003, see page 62

# EU1. EUROSABOT

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

*For photo of Roger Lundén, see page 49*

EUROSABOT

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

Tread braked railway vehicles radiate high rolling sound caused by the brake blocks generating roughness (waviness, corrugation) on the wheel tread, which induces vibrations and noise. The objective of EuroSABOT and the EU1 project was to develop new and better brake blocks that cause less roughness on the wheel tread than the cast-iron blocks used previously. 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 Hans Johansson assisted.

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

Mr Hans Johansson, Technician of Chalmers Applied Mechanics, at the brake test rig in Surahammar. Photo taken 2000. During Stage 3 Hans Johansson has contributed to projects TS5 and SD4



# 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 photo of Jens Nielsen, see page 19*

Silent Freight

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

The objective of Silent Freight and the EU2 project was a reduction of the noise level from the rolling stock used in freight traffic by 10 dB(A). CHARMEC's contribution 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 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 1000 Hz. A prototype wheelset manufactured by Adtranz Wheelset (now Lucchini Sweden) was used in the final field tests at Velim in the Czech Republic in May/June 1999.

Docent Jens Nielsen led the EU2 project. See further the CHARMEC Triennial Report from Stage 2.

# 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

*For photo of Jens Nielsen, see page 19*

Silent Track had overall a budgeted project cost of KEURO 3747 and a budgeted EU funding of KEURO 2075. Chalmers/CHARMEC's share of the EU funding was KEURO 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 coordinated 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 develop further the DIFF model (see under project TS1) for studying 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 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 further the CHARMEC Triennial Report from Stage 2. Two new publications are listed below.

Martin Hiensch, Jens Nielsen and Edwin Verheijen: Rail corrugation in the Netherlands – measurements and simulations, *Wear,* vol 253, nos 1-2, 2002, pp 140-149 (revised version of conference paper)

Jens Nielsen: Numerical prediction of rail roughness growth on tangent railway tracks, *Journal of Sound and Vibration,* vol 267, no 3, 2003, pp 537-548



# 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 photo of Lennart Josefson, see page 38*

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

The aim of ICON and the EU4 project was to develop and verify a calculation model that can describe the initiation and early growth of cracks in the railhead. The activities within projects EU4 and MU6 were similar and coincided to a great extent. Here we refer to the report in the former under project MU6.

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

For the EU projects, it should be observed that the entry "budgeted project cost" includes the full costs borne by the industrial partners but excludes about half of the total costs borne by the university. For the projects EU6, EU7 and EU8, these additional costs at Chalmers are given as "Budget CHARMEC".

# EU5. EUROBALT II

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

*For photo of Roger Lundén, see page 49*

EUROBALT II had an overall budgeted project cost of KEURO 4154 and a budgeted EU funding of KEURO 2320. Chalmers/CHARMEC's share of the EU funding was KEURO 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 well 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. A routine was implemented for optimal selection of the parameters describing the behaviour of the track.

Professors Tore Dahlberg and Roger Lundén led the EU5 project. See further the CHARMEC Triennial Report from Stage2. Two of the reports by Tore Dahlberg from our four Work Packages (WP) are

WP1: Review of works performed in WP1 of the EUROBALT II project, State-of-the-art, *EUROBALT Report 6C/000817/T1/DA,* August 2000, 12 pp

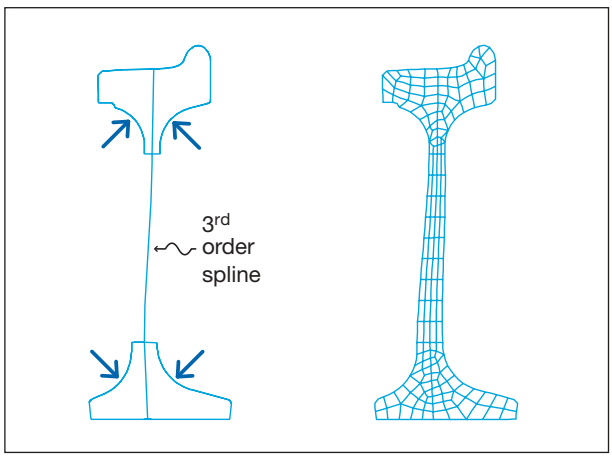
WP4: Developments in the EUROBALT II project of the computer program DIFF for train/track interaction simulation, *EUROBALT Report 4C/000707/T/OA,* July 2000, 18 pp

A late journal paper is

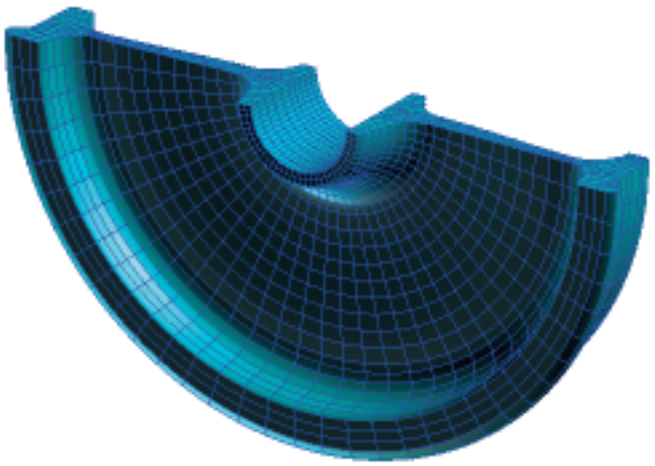
Tore Dahlberg: Some railroad settlement models – a critical review, *IMechE Journal of Rail and Rapid Transit,* vol 215, no F4, 2001, pp 289-300

Contributions to EU5 (track non-linearities and stochastic scatter) by Johan Oscarsson have been reported under project TS1.

Professor Tore Dahlberg of Linköping Institute of Technology




Optimizing the cross-sectional shape in project EU6



Finite element model in project EU6

# 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 – 2003-06-30 (– 2004-03-31) |
| *Budget EU* | KEURO 141 |
| *Budget CHARMEC* | Stage 3: KEURO 1200 |

*For photos of project leader and co-workers, see pages 19, 40 and 49*

The HIPERWHEEL project of the Fifth Framework Programme comprises a total of 280 man-months, and it has a budgeted project cost of KEURO 3690 and a budgeted EU funding of KEURO 1979. Chalmers/CHARMEC's commitment to HIPERWHEEL is 13 man-months. Partners in the project are Centro Ricerche Fiat (Italy), Chalmers Applied 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), Department of Mechanical Engineering at University of Sheffield (UK) and Valdunes (France). The duration of the HIPERWHEEL project is 48 months and it is co-ordinated by Centro Ricerche Fiat.

Outstanding safety, lower weight, longer maintenance intervals and less noise radiation are properties of future wheelsets that the HIPERWHEEL project aims at attaining. Mechanisms of damage such as rolling contact fatigue of the tread and fretting fatigue in the shrink-fit or press-fit between wheel and axle are to be considered. CHARMEC's main responsibility in the EU6 project, in collaboration with the University of Sheffield, is to study damage mechanisms and to act as task leader for "Numerical procedure for NVH analysis" (Work Package WP5). Meetings with our partners have been held in Darmstadt (Germany), Lovere, Milano and Orbassano (Italy), Meinerzhagen (Germany), Sheffield (UK), Valencia (Spain) and Gothenburg.

Our work in WP3 "Damage mechanisms acting on the wheelset and database for fatigue life predictions" has been completed. We have developed an "engineering" model for analysis of rolling contact fatigue of railway wheels. It is based on three fatigue indices and is coupled to models for simulation of the running dynamics of bogie and wheelsets, see further information on FIERCE under project MU9. In addition our work in WP4 "CAE-based procedure for wheelset durability assessments" has been finalized.

A numerical procedure for multidisciplinary optimization of wheelsets, based on a parametric FE model and on statistical trial planning and automated computer-program execution, has been developed by us in WP5 in collaboration with the company Ingemansson Technology in Gothenburg and Jönköping. The commercial programs PATRAN, NASTRAN, MATLAB and TWINS have here been combined for calculation of weight, modal parameters, fatigue stresses and noise radiation. LMS/OPTIMUS has been used to execute and monitor the other software, visualize the space of the design parameters and search for an optimum design. The aim is to find a design that minimizes both the dynamic contribution to the contact forces between wheel and rail (due to a reduced unsprung mass) and noise radiation (due to an optimized form of the wheel cross-section combined with a surface layer of damping applied to the web), while the wheel's fatigue strength is maintained. Examples of design variables are wheel radius, web thickness, lateral offset between ring and hub, transfer radii between ring, web and hub, and thickness of damping layer.

Our work on fretting fatigue of railway axles in the contact zone with the wheel hub (press fit or shrink fit) is in its closing phase, see below.

Anders Ekberg, Elena Kabo and Hans Andersson: Predicting rolling contact fatigue of railway wheels (see under project MU9)

Mauro Cavalletti, Anders Ekberg, Alan Facchinetti, Giampaolo Mancini and Maurizio Stanca: Prediction of rail vehicle mission loads and RCF damage by multibody modelling, *Proceedings 1st MSC.ADAMS European User Conference,* London (UK) November 2002, 12 pp on CD

Anders Ekberg, Elena Kabo and Hans Andersson: An engineering model for prediction of rolling contact fatigue of railway wheels (see under project MU9)

Anders Ekberg: Predicting fretting fatigue of railway wheel/axle assemblies – a state-of-the-art survey, *Chalmers Applied Mechanics,* Gothenburg 2003 (in progress)

Anders Ekberg: Numerical prediction of fretting of railway axles, *Proceedings International Seminar on Railway Axles at Imperial College,* London (UK) September 2003, 37 pp on CD

# EU7. INFRASTAR

INFRASTAR – Improving railway infrastructure productivity by sustainable two-material rail development

Verbesserte Produktivität der Eisenbahninfrastruktur durch Entwicklung haltbarer Schienen aus zwei Werkstoffen

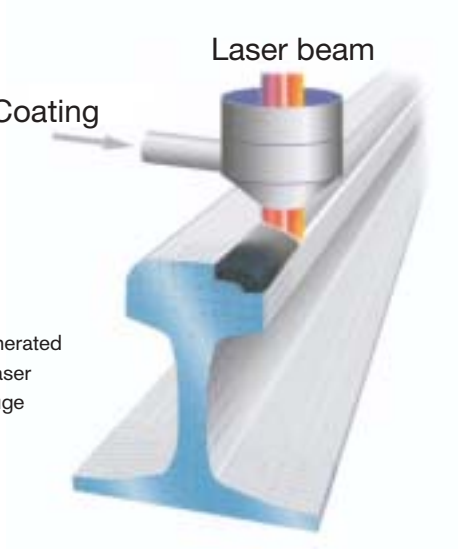
Amélioration de la productivité de l'infrastructure ferroviaire par le développement des rails durables composés de deux matériaux

| | |
|---|---|
| *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 – 2003-06-30 (– 2003-10-31) |
| *Budget EU* | KEURO 181 |
| *Budget CHARMEC* | Stage 3: KEURO 2100 |

*For photos of project leaders and co-workers, see pages 19, 38, 41, 43 and 49*

The INFRASTAR project of the Fifth Framework Programme comprises a total of 140 man-months with a budgeted project cost of KEURO 1780 and a budgeted EU funding of KEURO 1080. Chalmers/CHARMEC's commitment to INFRASTAR is 20 man-months. Partners are AEA Technology Rail (the Netherlands), Banverket (Sweden), Chalmers Applied Mechanics/CHARMEC (Sweden), Duroc (Sweden), Inexa Profil (Sweden, only to September 2001), RATP (France), Corus (France) and the Department of Mechanical Engineering at University of Sheffield (UK). The duration of the INFRASTAR project is 42 months and it is co-ordinated by AEA Technology Rail.

The aim of the INFRASTAR project is to increase the operational life and reduce the emitted noise of particularly exposed sections 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 is investigated. Two different technologies are being studied: the melting of powder onto the surface by means of a laser beam, and the rolling-in of an extra layer of material on the bloom during rail manufacture. One objective is to develop and validate a predictive model that can assist coating selection in the design of a fatigue-resistant two-material rail. We have participated in meetings with the project partners at Arlanda, Gothenburg and Luleå (Sweden), at Manchester and Sheffield (UK), at Metz and Paris (France) and at Utrecht (the Netherlands).




Computer-generated rendering of laser coating of gauge corner of rail (courtesy Duroc Rail)

We have established rigid-body models of trains on Malmbanan (the Iron Ore Line in northern Sweden) and on the Paris underground. Dynamic simulations of trains running on curves have been performed with the aid of the commercial computer program GENSYS, which calculates the contact forces between wheels and rail and where on the railhead contact takes place. Full-scale tests have been performed on Malmbanan and the Paris underground on stretches where laser-cladded rail had been installed in the track.

Three-dimensional finite element calculations of the stress field in the railhead at the contact patches between wheel and rail have been performed by us. Shakedown diagrams have been designed for the laser-cladded rail in collaboration with the University of Sheffield. The risk of initiation of rolling contact fatigue cracks can thus be estimated on the basis of such parameters as contact pressure, friction coefficient, thickness of surface layer, and material properties of the surface layer and the base material. A full finite element simulation of the laser-cladding process to quantify the residual stress field and its effect on the initiation of fatigue cracks is under way. Measurements of the residual stresses in twin-disc experiments (as performed in Sheffield) by use of strain gauges and centre hole drilling have been carried out by us but were complicated by the extreme hardness of the surface layer.

Martin Hiensch, Ajay Kapoor, Lennart Josefson, Jonas Ringsberg, Jens Nielsen and Francis Franklin: Two-material rail development to prevent rolling contact fatigue and to reduce noise levels in curved rail track, *Proceedings 5th World Congress on Railway Research (WCRR 2001),* Cologne (Germany) November 2001, 16 pp on CD. At the congress this work was awarded the prize for best paper in its category

→

# EU8. ERS

| | |
|---|---|
| *Project leader* | Professor Roger Lundén, Applied Mechanics |
| *Co-workers* | Mr Martin Helgen, MSc, and Docent Jan Henrik Sällström, both of Epsilon HighTech |
| | Mr Tore Vernersson, Applied Mechanics |
| *Period* | 2002-09-01 – 2003-06-30 (– 2005-08-31) |
| *Budget EU* | KEURO 206 |
| *Budget CHARMEC* | Stage 3: KEURO 200<br>Stage 4: KEURO 1000 |

*For photos of project leader and co-workers, see pages 49 and 74*

The ERS (Euro Rolling Silently) project of the Fifth Framework Programme comprises a total of 317 man-months with a budgeted project cost of KEURO 5880 and a budgeted EU funding of KEURO 2470. Chalmers/CHARMEC's commitment to ERS is 20 man-months. Partners in the project are 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 RÜTGERS Rail (formerly RÜTGERS Automotive, Italy). The duration of the ERS project is 36 months and it is co-ordinated by SNCF.

The aim of the ERS project is to develop new so-called "LL" type brake blocks for tread braked freight wagons (there are presently ca 650,000 of them 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 (i) should 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. Further, 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 (vi) should be environmentally friendly and, finally, (vii) the remains of worn blocks should be recyclable.

CHARMEC's investment in the project consists partly of a description of state-of-the-art and partly of thermomechanical simulations. Our work is being carried out in collaboration with the consultancy Epsilon HighTech. Volvo Technology will probably be engaged as subcontractor in a "brake block technology" investigation.

Our state-of-the-art report was first presented at a technical meeting in Paris on 27 November 2002 with Roger Lundén and Jan Henrik Sällström participating. The report was approved by the EU partners in September 2003. On 20 May 2003 Roger Lundén and Martin Helgen attended a technical meeting with representatives from SNCF and DB to discuss the thermomechanical simulations. It was decided that the tread braking tests performed on the inertia dynamometer at SNCF should be simulated. Three kinds of block materials, i e, cast iron, organic composite and sinter material, should be studied for two wheel designs. Heat transfer to the rail has been studied separately for a tread braked wheel, the work being co-ordinated with that in project SD4.

Jan Henrik Sällström, Martin Helgen, Tore Vernersson and Roger Lundén: ERS state-of-the-art report, Version 3, *Chalmers Applied Mechanics,* Gothenburg September 2003, 43 pp + Appendix 71 pp

Ajay Kapoor, Jonas Ringsberg, Lennart Josefson and Francis Franklin: Shakedown limits in three-dimensional wheel-rail rolling-sliding contacts, *Proceedings 8th International Fatigue Congress FATIGUE '2002,* Stockholm (Sweden) June 2002, vol 2, pp 1365-1372

Martin Hiensch, Francis Franklin, Jens Nielsen, Jonas Ringsberg, Geert-Jaap Weeda, Ajay Kapoor and Lennart Josefson: Prevention of RCF damage in curved track through development of the INFRA-STAR two-material rail, *Fatigue & Fracture of Engineering Materials & Structures,* vol 26, no 10, 2003, pp 1007-1017

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, *Proceedings 6th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2003),* Gothenburg June 2003, vol I, pp 39-47

Martin Hiensch: Two-material rail combats rolling contact fatigue, *Railway Gazette International,* September 2003, pp 587-590

Martin Hiensch, Per-Olof Larsson, Olof Nilsson, Didier Levy, Ajay Kapoor, Francis Franklin, Jens Nielsen, Jonas Ringsberg and Lennart Josefson: Development of a two-material rail for RCF and noise control, *Proceedings 6th World Congress on Railway Research (WCRR 2003),* Edinburgh (UK) October 2003, 12 pp

## SP1. LUCCHINI SWEDEN AB (bilateral agreement)

Bilateral agreements have run since 1987 between Lucchini Sweden (formerly Sura Traction, ABB Sura Traction 1990-96, Adtranz Wheelset 1996-2000) and Chalmers Applied Mechanics (formerly Chalmers Solid Mechanics). Our personnel have assisted the company in the design, testing and marketing of wheelsets. One recent activity is reported in the paper (where the second author listed is an employee of Lucchini's)

> Roger Lundén, Jürgen Schneider and Tore Vernersson: New wheelsets for 25 and 30 tonne axle loads, *Presented at 6. Internationale Schienenfahrzeugtagung,* Dresden (Germany) October 2003, 6 pp

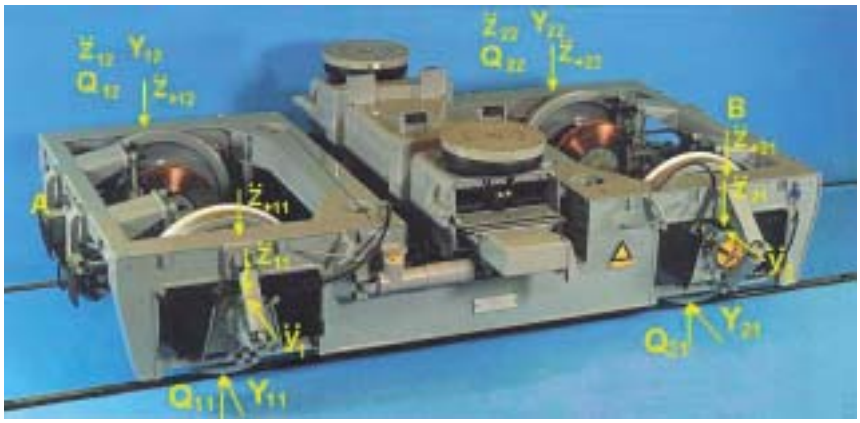


## SP2. NOISE FROM SWEDISH RAILWAYS

CHARMEC has been engaged in Banverket's overall efforts to reduce the noise emitted from Swedish railways. Results from the projects VB4, EU2 and EU3 are being exploited. The first meeting with CHARMEC was held in Gothenburg on 24 January 2002 with participants from Banverket's Head Office and Western Track Region.



## SP3. TRACK FORCE MEASUREMENTS ON X2




Instrumentation of non-powered X2 bogie as used during the track force measurements in October 2002 (courtesy TrainTech Engineering Sweden)

A new extensive test campaign with in-field measurements of the track forces caused by the Swedish high-speed train X2 was commenced by TrainTech Engineering and CHARMEC. Meetings to discuss and plan the campaign were held at TrainTech Engineering's premises in Stockholm on 13 December 2001 and on 21 February, 21 March and 10 October 2002. Collaborating organizations in the planning have been Banverket, Bombardier Transportation, CHARMEC, Ingemansson Technology, KTH Railway Technology, Lucchini Sweden, TrainTech Engineering and TrainTech Test Centre. The cash and in-kind financing (about MSEK 3.0) came from Banverket, Lucchini Sweden, SJ AB and CHARMEC.

The measurements were performed on 21-25 October 2002 with a train of type X2 in which a bogie had been equipped by TrainTech Test Centre with accelerometers and measuring wheels and with a data collection system. The train ran three times Stockholm – 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. Preliminary results of the measurements have been used to identify stretches of track where maintenance is needed. The full data are presently being evaluated by TrainTech Engineering and Ingemansson Technology. A dynamic finite element analysis of a trailing X2 wheel and a parallel dynamic measurement have been performed by the latter company.

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

For the period 1 January 2002 – 30 June 2003, bilateral agreements were made between Chalmers/CHARMEC and the Austrian switch manufacturer VAE AG (regarding projects TS7 and MU14) and the Austrian rail producer voestalpine Schienen GmbH (regarding projects MU11 and MU14) respectively. The financial contribution to CHARMEC in each agreement was KEURO 45 in cash. Beginning 1 July 2003 the two Austrian companies have joined CHARMEC's Industrial Interests Group under the joint name voestalpine Bahnsysteme, see page 79.



## SP6. DEVELOPMENT OF A QUIET RAIL

On 7 September 2000, the CHARMEC Board decided to start a development project aiming at treatment and installation of rails with less noise radiation. Dr Claes Fredö of the consultancy Ingemansson Technology AB was engaged in the work. Preparatory experiments were performed in the Chalmers Applied Mechanics laboratory to find out how much of the total noise is emitted from the separate parts (foot, web, head) of the rail. Different shielding arrangements and absorbing materials are now being tested. New solutions may reduce the noise by up to about 10 dB(A). Results from the Silent Track project EU3 have been exploited.

Dr Claes Fredö of Ingemansson Technology



## SP7. LATERAL TRACK STABILITY

Photo: Frida Hedberg, Aftonbladet Bild

Together with SP Swedish Testing and Research Institute, CHARMEC has conducted an investigation for Banverket of the lateral shift and stability of the ballasted track under high compressive forces. These forces originate from unintentional axial rail slip during braking or acceleration and/or from high summer temperatures (heat buckling, sun kinks). A vehicle negotiating a curve will induce both axial and lateral forces where the latter tend to push the track outwards.

Elena Kabo, Anders Ekberg and Lars Jacobsson: Track stability – a state-of-the-art survey (preliminary version), *Chalmers Applied Mechanics,* Gothenburg November 2003, 70 pp

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 during braking of the train

# ACADEMIC AWARDS

The research in railway mechanics at Chalmers University of Technology has resulted in the conferring of the higher academic degrees (above the Master's level) as listed below.

*Licentiate (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 |

*Doctor (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 |

*Docent (highest academic qualification in Sweden)*

| | |
|---|---|
| Roger Lundén | 1993-03-23 |
| Jens Nielsen | 2000-11-09 |


Recent licentiate theses and doctoral dissertations submitted by CHARMEC researchers

# INTERNATIONAL CONFERENCES

During Stage 3 (and the months immediately following upon Stage 3) researchers from CHARMEC have participated in, and contributed to, the following major seminars, workshops, symposia, conferences and congresses:

The 5th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems in Tokyo (Japan) 25-28 July 2000

The European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2000) in Barcelona (Spain) 11-14 September 2000

The 13th Nordic Seminar on Computational Mechanics (NSCM-13) in Oslo (Norway) 20-21 October 2000

The 2nd International Workshop on Wave Propagation, Moving Loads and Vibration Reduction (WAVE 2000) in Bochum (Germany) 13-15 December 2000

The seminar "Why Failures Occur in the Wheel Rail System" in Derby (UK) 22 May 2001

The 7th International Heavy Haul Conference in Brisbane (Australia) 10-15 June 2001

The 6th International Conference on Biaxial/Multiaxial Fatigue and Fracture in Lisbon (Portugal) 25-28 June 2001

The 2nd European Conference on Computational Mechanics (ECCM 01) in Cracow (Poland) 26-29 June 2001

The 8th International Congress on Sound and Vibration in Hong Kong (China) 2-6 July 2001

The 17th IAVSD (International Association for Vehicle System Dynamics) Symposium, Dynamics of Vehicles on Roads and Tracks, in Copenhagen/Lyngby (Denmark) 20-24 August 2001

The 13th International Wheelset Congress in Rome (Italy) 17-21 September 2001

The 14th Nordic Seminar on Computational Mechanics (NSCM-14) in Lund (Sweden) 19-20 October 2001

The 7th International Workshop on Railway Noise (IWRN) in Portland ME (USA) 24-27 October 2001

The 5th World Congress on Railway Research (WCRR 2001) in Cologne (Germany) 25-29 November 2001 (participation only in form of a co-authored paper)

The 10th International Conference on Fracture (ICF) in Honolulu HI (USA) 2-6 December 2001

The International Railway Conference on Switches and Crossings in Delft (the Netherlands) 19-20 March 2002

The 8th International Fatigue Congress, FATIGUE 2002, in Stockholm (Sweden) 2-7 June 2002

The 18th Symposium on Nordic Concrete Research in Elsinore (Denmark) 12-14 June 2002

The 1st International Conference on Brakes and Wheels in Paris (France) 13-14 June 2002

The conference "Railway Engineering 2002" in London (UK) 3-4 July 2002. "Railway Engineering" is an annually recurring conference

The 5th World Congress on Computational Mechanics (WCCM V) in Vienna (Austria) 7-12 July 2002

The 6th International Conference on Motion and Vibration Control (MOVIC 2002) in Saitama (Japan) 19-23 August 2002

The Workshop on Rolling Contact Fatigue, Applications and Development, in Brescia (Italy) 15 November 2002

The 2nd International Conference on Thermal Process Modelling and Computer Simulation in Nancy (France) 31 March – 2 April 2003

The 7th International Conference on Computational Plasticity (COMPLAS 2003) in Barcelona (Spain) 7-10 April 2003

The Workshop on the Application of Fracture Mechanics to Railway Components in Geesthacht (Germany) 15-16 April 2003

The 6th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2003) in Gothenburg (Sweden) 10-13 June 2003

The 3rd Scientific and Engineering Conference "XXI Century Rolling Stock (ideas, requirements, projects)" in St Petersburg (Russia) 3-5 July 2003

The 10th International Congress on Sound and Vibration in Stockholm (Sweden) 7-10 July 2003

The 10th International Symposium on Plasticity and Its Current Applications 7-11 July 2003 in Québec (Canada)

The 7th US National Congress on Computational Mechanics in Albuqerque NM (USA) 28-30 July 2003

The 21st International System Safety Conference (ISSC 21) in Ottawa (Canada) 4-8 August 2003

The 18th IASVD (International Association for Vehicle System Dynamics) Symposium, Dynamic of Vehicles on Roads and Tracks, in Atsugi, Kanegawa (Japan) 25-29 August 2003

The 2nd International Conference on Brakes and Wheels in Paris (France) 8-9 September 2003

The International Seminar on Railway Axles at Imperial College in London (UK) 25-26 September 2003

The 6th World Congress on Railway Research (WCRR 2003) in Edinburgh (UK) 28 September – 1 October 2003

The 1st International Conference on Adaptive Modeling and Simulation (ADMOS) in Gothenburg (Sweden) 29 September – 1 October 2003

The 7th International Seminar on Numerical Analysis of Weldability in Graz-Seggau (Austria) 29 September – 1 October 2003

# CONFERENCE CM2003 AT CHALMERS

The 6th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2003) was arranged by CHARMEC at Chalmers on Tuesday 10 – Friday 13 June 2003 under the chairmanship of Roger Lundén and Björn Paulsson. A total of 207 delegates from 25 countries participated, with Sweden (78), Germany (20), UK (17) and Japan (10) forming the largest contingents. The delegates came from academia (65), manufacturing industries (53), railway administrations and operations (32), institutes (27), consultancies (19) and other (11). The conference programme included 4 invited keynote lectures and 14 other plenary presentations. The remaining 63 works were presented in three parallel sessions. The total of 81 contributions accepted came from 16 countries with Sweden (14), UK (14), Japan (9) and Russia (7) dominating. The conference was planned by a national organizing committee chaired by Roger Lundén and Björn Paulsson with 15 representatives from Swedish universities and railway enterprises.

Opening and welcome speeches were delivered by Björn Paulsson and by Jan-Eric Sundgren, President of Chalmers, and Drewin Nieuwenhuis, General Manager of UNIFE. Among the prominent lecturers invited to CM2003 was Professor Emeritus K L Johnson from Cambridge University Engineering Department, UK. He is one of the pioneers in contact mechanics and tribology, and he is also a well-known textbook author.

In parallel with the conference an exhibition was held in which 15 companies and other organizations presented themselves. Printed conference proceedings were distributed to the delegates when they arrived and a special paper in Railway Gazette International had been compiled and published, see below. About half of the conference papers are being further reviewed for publication in a special issue of the scientific journal Wear.

Dr Joe Kalousek of NRC, Canada, during boat trip to Marstrand

The conference fee was set at SEK 7000 with a reduction to SEK 3500 for students (SEK 100 is about EURO 11). In addition, on 21 September 2000, the CHARMEC Board had decided to contribute KSEK 200 to the conference. Taking also into account the contribution KSEK 229 from Sponsors and the fees KSEK 139 from Exhibitors, and disregarding the work input from the local organizers at Chalmers, the conference resulted in a positive economic


At registration desk of CM2003, from left: Surahammar wheel for new locomotive on the Iron Ore Line, Anne-Marie Holmdahl, Björn Hellström, Carina Schmidt, Murray Hughes and Roger Lundén. AMH and CS are secretaries of Chalmers Applied Mechanics; Mässhuset Björn Hellström AB arranged the CM2003 exhibition; MH is Editor-in-Chief of Railway Gazette International


balance of about KSEK 730. The Department of Applied Mechanics had given a guarantee of KSEK 200, which accordingly was not implemented.

The City of Gothenburg invited all delegates to a reception in the City Hall on Wednesday. The conference banquet was held on Thursday evening in the fortress on Marstrand island north of Gothenburg. A two-and-a-half-hour boat trip through the archipelago took the delegates to Marstrand.

Dr Joe Kalousek of the National Research Council (NRC) in Vancouver, Canada, has been the chairman of the Advisory Group of the International Committee for the present conference series. The Committee met in Gothenburg on 10 June 2003 and Professor Roger Lundén was elected new chairman of the Advisory

Professor Emeritus K L Johnson of Cambridge University Engineering Department lecturing at CM2003

Group. It was also decided that the next conference be held in Australia in 2006. On 2-5 May 2003, Roger Lundén had visited Joe Kalousek in Vancouver.

Anders Ekberg, Elena Kabo and Jonas Ringsberg (editors): *Proceedings 6th International Conference on Contact Mechanics and Wear of Rail/Wheel Systems (CM2003),* vols I & II (ISBN 91-631-3928-6 & 91-631-3929-4) + Appendices I, II & III, 572+19+24+14 pp

Anders Ekberg, Elena Kabo, Jens Nielsen and Jonas Ringsberg: Researchers on the track of wheel-rail interaction, *Railway Gazette International,* June 2003, pp 397-399

Dr Peter Pointner of voestalpine Schienen delivering his Keynote Lecture at CM2003

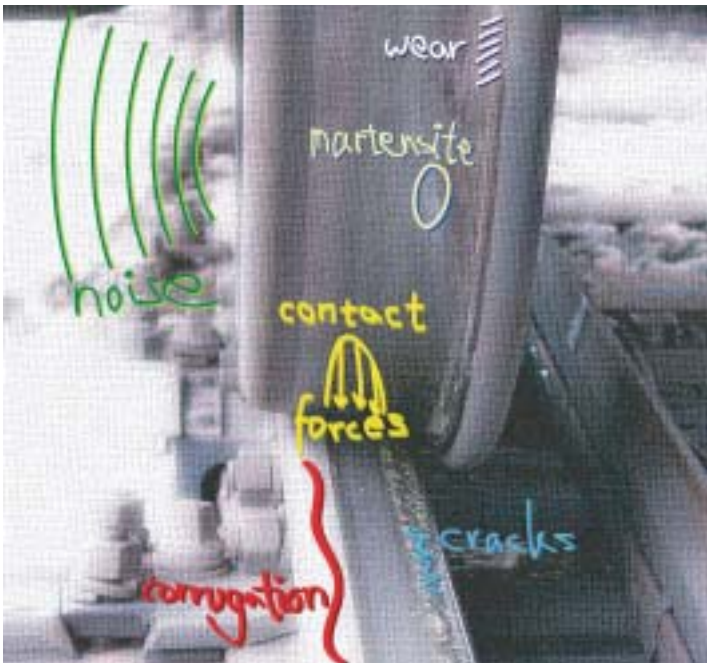



Illustration of the topics dealt with at the conference CM2003. From Railway Gazette International June 2003

At the end of CHARMEC's Stage 3, the partners in the Industrial Interests Group of that Stage expressed the following views (with the exception of SL Infrateknik, which did not join until 1 January 2003).

### Abetong Teknik

CHARMEC has provided Abetong Teknik with an outstanding research environment. Among the advantages accruing from this environment has been the employment by us of a PhD trained in the fields of major interest to us as suppliers of precast concrete sleeper technology. With ever increasing demands on the performance of fixed track installations, in which concrete sleepers play a significant role, and the tendency of the end users to base their technical specifications on fairly general and approximate technical standards, it is of the greatest importance to be able to offer alternative sleeper designs based on specific track conditions. With our new in-house PhD and with access to the entire knowledge bank within CHARMEC we can now offer designs of concrete sleepers suited for track conditions relevant to the respective railway organization and with far better technical and economic performance than a sleeper designed on the basis of the general standards adopted. Abetong Teknik can today see a great potential in the knowledge accumulated by CHARMEC. By combining many of the research results it should be possible to transform the academic tools into practical design tools, useful in the industry.

Our participation in CHARMEC has provided us with a fuller understanding of the functioning of the entire track structure including all its components and their related problems. This understanding has significantly improved our ability to engage in professional discussions with the end users of our concrete sleepers. Seen and accepted as part of the integral track structure, the sleepers can now more effectively be optimized. Alternative designs have been evaluated in collaboration with CHARMEC researchers. The knowledge gained will also be useful in the development of a new generation of ballast-free slab-track. The Abetong licensees abroad have shown an increasing interest in the research results emanating from CHARMEC, and initiatives have been taken to develop a further exchange of knowledge.

### Banverket Headquarters

CHARMEC research has helped Banverket to develop track structures 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. For instance, the upgrading 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 MEURO 50 for the two companies LKAB (iron ore) and Stora Enso (paper and forest products) that use these lines for their freights.

During CHARMEC's Stage 3, the development of new projects on track switches has been an important step forward. Today, Banverket spends about MEURO 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 SP Swedish Testing and Research Institute on lateral track stability and safety against track buckling.

### Bombardier Transportation Sweden

Bombardier Transportation Sweden has been a partner in CHARMEC since 1 July 2000. The company has since then changed owner and name (formerly Adtranz Sweden). One reason for our joining CHARMEC was that our subsidiary Adtranz Wheelset, through which we previously had access to CHARMEC, was sold to the Lucchini Group. The projects on wheelsets, both regarding rolling contacts and cracks in wheels, are important for our understanding of the behaviour of railway wheels in traffic. Recently we have been active in initiating a new CHARMEC project on new wheel materials, which was partly inspired by winter problems experienced with some of our trains. Further, the CHARMEC work on railway noise is of great importance in our aim to develop quieter trains. Our ambitions for improving the vibrational behaviour of trains are reflected in the fact that we have been active in initiating three new CHARMEC projects in this area. We believe that the results from these projects will be of major importance when we develop new systems and components for bogies and car bodies.

### Duroc Rail

Duroc has been a member of the competence centre since 1997. The subsidiary Duroc Rail is a small company which means that access to know-how and research results etc would not have been possible without membership in CHARMEC. In February 2003, a thesis for the degree of Licentiate of Engineering regarding properties

of laser-cladded railway steel was presented. The knowledge derived from this research, as well as from another research project into the microstructures under the cladding, is of great importance to us. The results will be exploited in a new EU project in the Sixth Framework Programme.

EU wants to triple the railway transportation volume in 15 years, and Sweden is in the forefront of developing tracks and trains for higher axle loads. As we see it, 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 plays 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 in-field testing for more than one year on the Iron Ore Line in northern Sweden and in the Paris underground. The results are promising.

### Green Cargo

The co-operation with CHARMEC has been important in our 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 us. Further, they have co-operated with us when testing and evaluating new composition brake blocks for low noise freight transports. The CHARMEC participation in the EU-project ERS is important for future development in this area.

### Lucchini Sweden

A significant achievement in our co-operation with CHARMEC during the last three years has been the development of new freight wagon wheelsets for 25 and 30 tonne axle loads suitable for the Nordic climate. These wheelsets have to fulfil stringent requirements to comply with various national and international standards. The brake test rig on our premises at Surahammar, earlier developed together with Chalmers, has been extremely important in this work. Further, the CHARMEC research work at the Railway Noise Test Rig (RNTR, also on our premises) is important for our long-term strategy to develop quieter railway wheels. The CHARMEC work on out-of-round wheels has been of great value in our work to improve our production techniques. Further, CHARMEC personnel have assisted us in marketing and in technical meetings with customers.

For the past two years our company (formerly Adtranz Wheelset) has belonged to the Italian Lucchini Group with subsidiaries in several countries in Europe. The competence and special knowledge within CHARMEC have been of great importance in our co-operation with the new owner, especially in our contacts with their research and development department in Italy. Synergy effects have already been achieved in that a new CHARMEC project on improved wheel materials to be conducted in collaboration with Lucchini in Italy has recently started. Another area of co-operation is the work on fatigue and cracks in railway wheels.

### SAB WABCO Group

The ongoing renewal of braking systems for railway freight wagons is driven by requirements for higher train speeds, increased axle loads and lower noise levels. SAB WABCO 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 in-field tests has been initiated by CHARMEC. The block braking of freight and passenger wagons should be optimized regarding 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) is of great value for us. SAB WABCO 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.

### TrainTech Engineering Sweden

The co-operation with CHARMEC has been of great value in our work to enhance the performance of the X2 high speed tilting trains. CHARMEC personnel have been active throughout the planning, execution, analysis and evaluation phases in our track force measuring campaign on X2. The methods and computer programs relating to high frequency train/track dynamics developed within CHARMEC have been implemented. This together with our employment of a PhD from CHARMEC has increased our knowledge and better equipped us in this important area of train operation. CHARMEC personnel have contributed to new wheelset designs for the X2 trains. CHARMEC has made important contributions at our annual meetings with Deutsche Bahn's Research and Technology Centre in Minden.

# PARTNERS IN INDUSTRY

The status reported below is of November 2003. The new partner voestalpine Bahnsysteme GmbH of Stage 4 has 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)

Manufacturer of prefabricated and pretensioned concrete structural components with 600 employees including subsidiary and sister companies in Sweden and abroad. Headquartered in Växjö. Belongs to the Heidelberg-Cement Group. Areas of interest are the design and manufacture of railway sleepers fitted with fastenings and pads for the rails. Of particular interest are tools useful for the identification of loads on sleepers installed in track and for the structural analysis and design of sleepers for main lines and turnouts. Also of interest is the proportion of noise emitted by the sleepers. The main buyers of sleepers are state railways and railway contractors. A total of around 3 million Abetong sleepers are produced annually in fully and partly owned and licensed sleeper plants at about 25 locations around the world.

### Banverket (1995 and 1990)

The Swedish National Rail Administration, abbreviated BV, is the country's infrastructure authority and manager with a total of 8000 employees. CHARMEC's partner is the headquarters at Borlänge with 400 employees. CHARMEC also co-operates with some regional offices. Areas of interest are the design, construction and maintenance of all sorts 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 track structure. It is especially important to understand and predict the influence on the track of proposed higher speeds and increased axle loads. Of primary importance to Banverket is also research concerning vibration, noise and safety.

### 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 2000 work in Sweden. The office in Västerås is one of the main engineering hubs for the division Intercity Trains. Also located on this site are the global Centres of Competence for Acoustics and Vibration and for Vehicle Dynamics. Areas of interest 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 of wheel-rail generated vibration into the bogie and car body, contact force identification, and the application of active control systems for enhanced comfort.

### Duroc Rail AB (1997)

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. However, the company's development work focuses on treatment 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 are 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.

### Green Cargo AB (2000)

State-owned Swedish logistic company with headquarters in Solna and with 3700 employees and an annual turnover of about MEURO 700. Green Cargo achieves about 12,000 million tonne-km of cargo annually and 770 million wagon-km (2002). Green Cargo has 450 locomotives and 9200 freight wagons. The former "SJ Godstransportdivisionen" (Freight Division of the Swedish State Railways) was incorporated at the turn of the year 2000/2001, changing its name to Green Cargo AB. Areas of interest in the co-operation with CHARMEC are braking, noise emission, and improved designs and materials for wheels and axles.

### Lucchini Sweden AB (1995 and 1987)
(formerly Adtranz Wheelset)

Railway wheelset manufacturer in Surahammar with 70 employees. The firm is a fully-owned subsidiary of the Lucchini Group in Italy (worldwide, Lucchini has about 10,000 employees in 10 countries). Areas of interest for Lucchini Sweden are the design, manufacturing, mounting, running, braking and maintenance of wheelsets. New materials for wheelsets and noise emission from wheels are of particular interest. The main buyers of the wheelsets are the passenger train operator SJ, the freight train operator Green Cargo and Bombardier Transportation Sweden, but export of products and services is becoming increasingly important.

### SAB WABCO Group AB (1997)

One of the largest railway brake system suppliers in the world with headquarters in Malmö and with production units in Sweden, Germany, France, Italy, UK and several other countries. The total number of employees is 1800, of whom 130 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, in particular, the interaction of brake block and wheel tread is of interest. New and better materials for the blocks are sought. SAB WABCO was recently sold by the Cardo Group to the investment fund Vestar.

### SL Infrateknik AB (2003)

SL (Storstockholms Lokaltrafik) is the Stockholm Urban Transit Authority. SL Infrateknik administers the operation, maintenance and renewal of all fixed railway installations, rolling stock and real estates within the Greater Stockholm Area railway network. The 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. These systems cater for about 1.3 million passenger trips every day. CHARMEC's partner is the headquarters in Stockholm, mainly the track and rolling stock departments. Areas of main interest are noise and vibration, track and vehicle maintenance, and materials. Of particular interest are the wear and dynamics of switches and also structure-borne noise and material fatigue problems. SL Infrateknik expects that the CHARMEC research projects will provide an increased understanding and thereby a better platform for improving technical solutions and maintenance work for track structure and rolling stock.

### TrainTech Engineering Sweden AB (1995 and 1992)

State-owned technical consultancy in the railway vehicle field with a total of 100 employees at the office in Solna and the Hagalund laboratories. The annual turnover is about MEURO 9 (2002). The former "SJ Teknikdivisionen" (Technical Division of SJ, the former Swedish State Railways) was incorporated in 2001. The EuroMaint company with its daughter TrainTech Engineering Sweden AB was then established. Areas of interest in the co-operation with CHARMEC are the design, mounting, running, braking and maintenance of railway wheelsets, especially life estimations and reprofiling practice for the wheels. Of particular interest are the mechanisms behind so-called wheel flats on the treads as caused by unintentional braking and sliding of the wheels. Also in great demand among TrainTech's customers is research into contact conditions wheel/rail, safety technology, noise problems, new materials and improved brake systems. In November 2003, TrainTech Engineering Sweden was sold to the British company Interfleet Technology.

### voestalpine Bahnsysteme GmbH (2003 and 2002)

The company voestalpine Schienen GmbH runs Europe's 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) quality. The rail rolling mill Thyssen Schienen Technik in Duisburg, Germany, also belongs to the company. Another branch of voestalpine Bahnsysteme is the manufacturer VAE AG of switches and crossings headquartered in Zeltweg, Austria, with several special track production companies worldwide. voestalpine Bahnsysteme has about 7000 employees. For the financial year 1 April 2002 – 31 March 2003 the sales of the voestalpine Group (including its steel division and some minor other divisions) amounted to MEURO 4392.

# PARTNERS IN EU PROJECTS

Our partners in CHARMEC's eight EU projects during Stages 1, 2 and 3 are listed under their names at time of contract signing. Some of them may lately have changed their names and affiliations.

### Adtranz Sweden
Now Bombardier Transportation Sweden. Swedish section of a multinational company which designs and manufactures railway transportation components and systems

### AEA
AEA Technology Rail BV is a consultancy based in Utrecht, the Netherlands, see NSTO below

### Banverket
The Swedish National Rail Administration (infrastructure authority) head-quartered in Borlänge

### Becorit
Becorit GmbH in Recklinghausen (Nordrhein-Westfalen) is a German supplier of friction materials for brakes

### Bremskerl
Bremskerl Reibbelagwerke GmbH in Estorf-Leeseringen (Niedersachsen) is a German supplier of friction materials for brakes

### BR Research
Research and development division of British Rail located in Derby (now owned by AEA Technology plc)

### BS
British Steel plc (now in the Corus Group plc) is a multinational steel producer with research facilities at several locations

### CAF
Construcciones y Auxiliar de Ferrocariles SA is a Spanish company designing and manufacturing trains

### CEIT
Centro de Estudios e Investigaciones Técnicas de Gipuzkoa is a Spanish non-profit research organization

### Cronau
Heinrich Cronau GmbH is a German company in Homburg (Saarland) specializing in construction and maintenance of railway tracks

### DB
Deutsche Bahn AG is the German State Railways with their research centre in Minden (Niedersachsen)

### Duroc
Duroc AB is a Swedish company with its branch Duroc Rail AB in Luleå doing wheelset maintenance and also surface treatment of wheels and rails by use of laser technology

### ERRI
European Rail Research Institute in Utrecht, the Netherlands, is the research organization within UIC (Union Internationale des Chemins de Fer)

### Federal-Mogul
Federal-Mogul Friction Products Ltd in Chapel en le Frith (Derbyshire), UK, is a supplier of friction materials for brakes (formerly Ferodo)

### FrenDo/ABEX
FrenDo/ABEX Rail is a supplier of frictional materials for brakes (now part of RÜTGERS Automotive)

### Ferodo
Ferodo plc, with Railway Division in Stockport (Manchester), UK, is a supplier of frictional materials for brakes (now part of Federal-Mogul)

### FIAT
Il Centro Ricerche FIAT (CRF) in Orbassano (Turin) is an Italian research organization dealing with ground vehicles

### Fraunhofer LBF
Fraunhofer-Institut für Betriebsfestigkeit LBF is a German establishment in Darmstadt performing experimental and numerical analyses of mechanical components for vehicles

### FS
Ferrovie dello Stato SpA is the Italian State Railways (now broken up into smaller parts). Our contact is with a department in Florence

### Honeywell
Honeywell Bremsbelag GmbH (formerly Jurid) in Glinde (Schleswig-Holstein) is a German supplier of friction materials for brakes

### ICER
ICER Materiales de Fricción SA in Pamplona (Navarra) is a Spanish supplier of friction materials for brakes

### Inexa Profil
Inexa Profil AB was a Swedish company in Luleå with a rolling mill for rails (closed down in October 2001)

### INSA
Institut National des Sciences Appliquées de Lyon is an engineering university and research institute in Lyon, France

### ISVR
The Institute of Sound and Vibration Research at the University of Southampton, UK

### Jenbacher
Jenbacher Transportsysteme AG is an Austrian company manufacturing components for railway vehicles

**Kassel University**
Universität Gesamthochschule Kassel in Germany. Our contact is with the Department of Geotechnics

**KTH**
The Royal Institute of Technology in Stockholm, Sweden

**Lucchini CRS**
Lucchini Centro Ricerca e Sviluppo is a research organization within the Italian Lucchini Group, which produces steel and manufactures rails and wheelsets

**MDI**
Mechanical Dynamics Italy in Bordano (Udine) is a subsidiary of Mechanical Dynamics Inc in USA which develops the ADAMS software

**Metravib**
Metravib RDS in Ecully (Lyon) is a French private contract research organization specializing in vibroacoustics

**NS**
Nederlandse Spoorwegen NV is the Dutch State Railways. Our contact is with two departments in Utrecht

**NSTO**
NS Technisch Onderzoek is the research organization within NS (now owned by AEA Technology Rail of UK and trading under the name AEA Technology Rail BV)

**Otto Fuchs**
Otto Fuchs Metallwerke KG in Meinerzhagen (Nordrhein-Westfalen) is a German industry which forges and extrudes nonferrous alloys

**Otto-von-Guericke-Universität**
University in Magdeburg, Germany. Our contact is with the Department of Mechanical Engineering

**Pandrol**
Multinational company developing and manufacturing rail fastening systems and components with its Group Research and Development Testing Facility in Worksop (Nottinghamshire), UK

**Politecnico di Milano**
Milan University of Technology in Italy. Our contact is with the Department of Mechanical Engineering

**Politecnico di Torino**
Turin University of Technology in Italy. Our contact is with the Department of Aeronautical and Space Engineering

**RATP**
Régie Autonome des Transports Parisiens is a Metro operator and track manager in Paris, France

**RÜTGERS Automotive**
RÜTGERS Automotive Italia SpA in Avellino (Campania) is the Italian branch of a supplier of friction materials for brakes with headquarters in Essen, Germany (formerly ABEX Rail)

**SBB**
Schweizerische BundesBahnen AG is the Swiss State Railways. Our contact is with the departments Zugförderung und Werkstätten and Infrastruktur/Anlagenmanagement in Bern

**SLM**
Schweizerische Lokomotiv- und Maschinenfabrik AG in Winterthur. SLM involves Sulzer-Innotec (research organization of Sulzer Corporation)

**Sogerail**
French manufacturer of rails in Hayange (close to Thionville). Now in the Corus Group

**SNCF**
Société Nationale des Chemins de Fer Français is the French State Railways

**Talbot**
Waggonfabrik Talbot Aachen in Germany is a rolling stock producer (now a subsidiary of Bombardier Transportation)

**TNO**
Nederlandse Organisatie voor Toegepast – Natuurwetenschappelijk Onderzoek is a contract research organization in Delft, the Netherlands

**Trenitalia**
Trenitalia SpA is the Italian State Railways' passenger transport company (formerly part of FS)

**TSO**
Travaux du Sud-Ouest is a French company with headquarters in Chelles (east of Paris) specializing in construction and maintenance of railway tracks

**TU Berlin**
Technische Universität Berlin in Germany. Our contact is with the Department of Luft- und Raumfahrt (which does research in railway mechanics)

**University of Sheffield**
University of Sheffield, UK. Our contact is with the Department of Mechanical Engineering

**Valdunes**
French wheelset manufacturer with sites in Valenciennes and Dunkirk

**Vibratec**
Industrial RTD company in Ecully (Lyon), France

Some of the events and achievements during Stage 3 and not reported elsewhere will be presented here.

### Board meetings relocated

Three of the twelve ordinary meetings of the CHARMEC Board during Stage 3 were combined with visits to, and information from, three industrial partners: 19-20 February 2001 to Adtranz Sweden in Västerås, 27-28 May 2002 to Banverket Headquarters in Borlänge, and 18-19 November 2002 to Abetong Teknik in Växjö.

### KTH, SP and NUTEK/VINNOVA

CHARMEC's earlier declaration of intent and agreement on co-ordination and co-operation with KTH Railway Technology and SP Swedish National Testing and Research Institute respectively, have been followed up during Stages 2 and 3. After 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 the KTH Railway Group. Several of CHARMEC's doctoral candidates have taken overview courses in railway technology given at KTH.

NUTEK's, and later VINNOVA's, liaison person with CHARMEC during Stage 3 was Carl Naumburg. The university liaison person was Roger Johansson, later succeeded by Chalmers' new Vice President for External Relations, Johan Carlsten.

The Director of CHARMEC along with some Chalmers researchers and representatives of the Industrial Interests Group participated in each of NUTEK's, and later VINNOVA's, Competence Centre Days on 25 October 2000 in Uppsala, 24 October 2001 in Luleå, 22 October 2002 in Stockholm and 6 November 2003 in Gothenburg.

### Semi-annual reports

Each six months, as of 31 December and 30 June, all CHARMEC leaders of ongoing projects write a two-page report on the progress of their projects during the past half year. As required by the Board, headline topics in each case cover 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 collected in a document submitted to the CHARMEC Board before their next meeting when they are studied and discussed. From 2003-06-30 onwards, all semi-annual reports are to be written in English.

### Workshop in Västerås

On the recommendation of the international evaluators in March 2000, a workshop (a retreat) was arranged in Västerås on 20 February 2001 for CHARMEC's project leaders, doctoral students and industrial partners. The workshop was led by Ms Ylva Navér of "Provins Fem" and was attended by 33 people. Among the proposals put forward were (i) better content and organization of the seminars held on the mornings of the Board meetings, (ii) the establishment of reference groups for the Centre's research projects, (iii) revision of the formulated "Vision and goals" in the previous Triennial Report, and (iv) improved means for transferring research results from the university to industrial partners. Implementation of these proposals has been pursued throughout CHARMEC's Stage 3.

### Project reference groups

As an outcome of the Västerås workshop of 20 February 2001 the CHARMEC Board has defined the role of a Project Reference Group (PRG) and recommended that all CHARMEC projects establish such a group. A PRG should be a forum for informal presentation and discussion of results and for planning of future activities (within the framework decided by the Board on 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 at least twice a year and the project leader is the convener. Several CHARMEC projects have now established a PRG. Some projects have a joint PRG.

### Information exchange with DB

Since 1999, a series of meetings has been organized for information exchange by DB (Deutsche Bahn) and SJ (TrainTech Engineering). Adtranz Sweden (Bombardier Transportation Sweden), Banverket, Duroc Rail and

CHARMEC have been invited to take part. The third meeting was held in Germany at the research centre in Minden and the maintenance shop in Nuremberg on 25-26 September 2000, and the fourth meeting in Sweden in Luleå and Malmberget on 11-13 June 2001. The fifth meeting took place in Germany in Munich on 3-4 September 2002. CHARMEC attended all these meetings.

### Abetong Teknik's symposium

On 29 May 2001, Abetong Teknik organized a symposium in railway mechanics for their worldwide licensees and other business partners. About 50 people from Austria, Denmark, Estonia, Finland, Lithuania, the Netherlands, Norway, South Africa, South Korea, Sweden and Switzerland attended. CHARMEC's researchers contributed with seven lectures. The symposium was held at Kungälv, Sweden.

### CRC in Australia

A co-operative Research Centre for Railway Engineering and Technologies, abbreviated Rail CRC, was started in Australia in 2001 with Professor Dudley Roach of Central Queensland University in Rockhampton as Chief Executive Officer. He visited CHARMEC on 4-5 October 2001 for discussions about the organization of our Centre. Later Roger Lundén was appointed member of the Technology Advisory Committee for Rail CRC. On 5-6 August 2003, Roger Lundén visited Rail CRC in Australia to take part in an evaluation of the standing of that Centre regarding quality and the relevance of its research programme.

Six Australian universities and five railway enterprises participate in Rail CRC which was established and is supported under the Australian Government's Cooperative Research Centres Program. 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". A co-operation between Rail CRC and CHARMEC is foreseen.

### Heavy haul

International Heavy Haul Association

CHARMEC's work to support the upgrading to 30 tonne axle load of the Iron Ore Line (Malmbanan/Ofotbanen) in northern Sweden and Norway has continued during Stage 3, see the CHARMEC Triennial Report from Stage 2, page 44. Our two contributions to the Brisbane conference have now been presented and published:

Roger Lundén, Thomas Nordmark and Björn Paulsson: Enhancing iron ore transportation in Sweden, *Proceedings 7th International Heavy Haul Conference,* Brisbane (Australia) June 2001, pp 91-106

Robert Fröhling, Tord Karlsson and Roger Lundén: New LKAB iron ore wagons with self-steering bogies and rapid unloading system, *ibidem,* pp 161-166

The 8th IHHC (International Heavy Haul Conference) will be held in June 2005 in Rio de Janeiro, Brazil. CHARMEC is a member of the local organization NHH (Nordic Heavy Haul).

Yet another report on heavy haul is

Roger Lundén, Johan Marais and Stefan Schrader: Developing wheelsets for 30 tonne axle loads, *Railway Gazette International,* September 2001, pp 631-634

Johan Marais is Principal Engineer at Spoornet Railway Engineering in Silverton, Pretoria, RSA, and Stefan Schrader Project Engineer at Bombardier Transportation in Kassel, Germany.

### Nordic seminars in railway technology

CHARMEC's researchers have presented their work at the annual Nordic seminars in Stockholm on 7-8 March 2001 (7 contributions), Borlänge on 14-15 March 2002 (10 contributions) and Copenhagen on 31 March – 1 April 2003 (2 contributions). These presentations have not been listed under the projects.

### Nordic Rail fair

At the 4th and 5th Nordic Rail fairs at the Elmia premises in Jönköping on 2-4 October 2001 and 7-9 October 2003, CHARMEC shared a stand with KTH Railway Group, VINNOVA and the Swedish Transport and Communications Research Board (VTI). Our research projects were displayed on wall plates, four seminars were held at each of the fairs (not listed under the projects) and printed material was distributed. Several valuable contacts with the railway industry have been (re)established at Nordic Rail. A report including a reproduction of the wall plates is

Bengt Åkesson: Chalmers Järnvägsmekanik (Chalmers Railway Mechanics, in Swedish), *SVIB VibrationsNytt,* vol 19, no 3, 2001, pp 22-29

### Swedish Mechanics Days

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

### Workshops at Smögen

Two international workshops on statistical analysis in fatigue were arranged at Smögen on the Swedish West Coast by the Stochastic Centre in Gothenburg. CHARMEC's Anders Ekberg and Elena Kabo participated together with other researchers from Italy, Japan, Sweden and the UK. On 14-25 August 2000 the topic concerned the application of stochastic geometry and the theory of extremes. On 19-23 August 2002 subjects treated included the fatigue impact of clusters of material defects of varying sizes and types.

### Workshop in Brescia

The workshop "Rolling Contact Fatigue: Applications and Developments" was held on 15 November 2002 at the University of Brescia, Italy. Anders Ekberg and Elena Kabo from CHARMEC were invited as international speakers together with representatives from Italian universities, industries and administrations. A total of 14 papers were presented on load spectra definition, stress and strain evaluation, crack propagation mechanisms and rolling contact fatigue sensitivity analysis. The workshop was organized by Professor Giorgio Donzella from Università degli studi di Brescia and Professor Stefano Beretta from Politecnico di Milano.

In connection with the workshop Anders Ekberg gave a four-hour lecture on rolling contact fatigue for graduate and doctoral students at the University of Brescia on 14 November 2002. The lecture was videotaped for educational purposes. See further under project MU9.

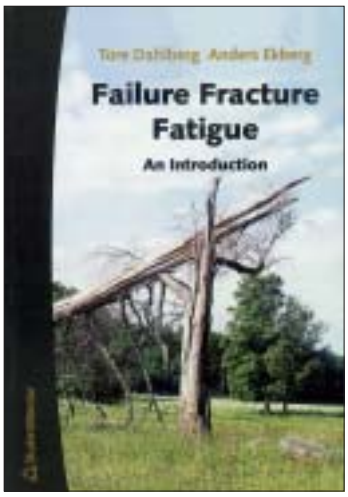
### Graduate course in contact mechanics

Eight of CHARMEC's doctoral candidates have taken a graduate course in contact mechanics given during autumn 2002 by Roger Lundén assisted by Anders Ekberg and Jonas Ringsberg. Several applications related to the wheel/rail interface. Rolling contact induced deformations and stresses, tribology and fretting were treated.

### Textbook on fatigue and fracture

Tore Dahlberg and Anders Ekberg have written a textbook (in English) related to the type of problems studied at CHARMEC. The book is presently being used in both intramural and extramural courses for undergraduate students and engineers employed in industry.

Tore Dahlberg and Anders Ekberg: *Failure, fracture, fatigue – an introduction,* Studentlitteratur, Lund (Sweden) 2002, ISBN 91-44-02096-1, 356 pp




Front cover of Failure, fracture, fatigue – an introduction

### Overview article in Vehicle System Dynamics

CHARMEC's Jens Nielsen was invited to present a keynote lecture in August 2003 at the 18th IAVSD Symposium, Dynamics of Vehicles on Roads and Tracks, in Japan, and to compile, along with co-authors, an overview article for the periodical Vehicle System Dynamics with the title "Train-track interaction and mechanisms of irregular wear on wheel and rail surfaces". The article (listed under project TS5) comprises 52 pages and contains 159 references. Causes, consequences and remedies are discussed for (i) short-pitch rail corrugation on tangent tracks and large radius curves, (ii) wheel corrugation as caused by tread braking, and (iii) wheel polygonalization. The state-of-the-art in modelling of dynamic train-track interaction in conjunction with prediction of irregular wear is reviewed.

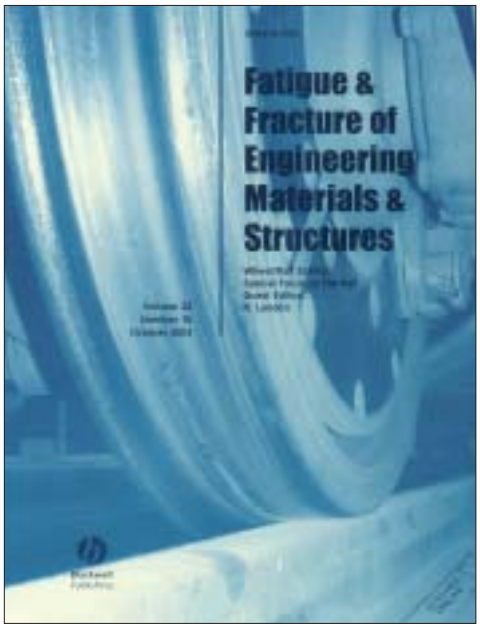
### Special issue of FFEMS

Roger Lundén was invited to be Guest Editor of a Special Issue of the international scientific journal Fatigue & Fracture of Engineering Materials & Structures (FFEMS). The German accident involving a broken wheel and derailment at Eschede on 3 June 1998 on the Hannover – Hamburg Line, see below, and the British accident with

the broken rail and derailment at Hatfield on the East Coast Main Line on 17 October 2000 set the framework for this issue.

The 72-page volume contains fourteen invited articles on wheel-rail safety with special focus on the rail. The authors represent leading research groups in ten countries. There are (i) three review articles, followed by eleven articles on (ii) monitoring, maintenance and non-destructive testing, (iii) damage, fatigue and fracture of rails, (iv) phenomena at the wheel-rail interface, and (v) new rail materials. A total of 360 references are quoted in the articles. The Special Issue starts with an Editorial and Introduction by the Guest Editor.

Roger Lundén (Guest Editor): Special Issue *Fatigue & Fracture of Engineering Materials & Structures,* vol 26, no 10, 2003, pp 861-1031




Front cover of Special Issue of FFEMS October 2003

## Eschede expertise

On 3 June 1998, a disastrous accident involving a German high-speed ICE train occurred at Eschede on the railway line between Hannover and Hamburg, with 101 people killed and more than 100 seriously injured. The accident started with a broken rubber-sprung tyre on a wheel of type BA64 resulting in the derailment of several coaches and the collision of these with the supports of a crossing road bridge. Roger Lundén and Bengt Åkesson of CHARMEC were engaged by the train operator Deutsche Bahn (DB) as private consultants and experts from August 1999 until May 2003, when the criminal case against two employees of DB and one employee of the wheel manufacturer was concluded.

In our extensive investigations of the fatigue properties of the wheel type that failed, we (Roger Lundén and Bengt Åkesson) have engaged the services of Epsilon HighTech Engineering for finite element calculations, ABB Corporate Research for chemical and corrosion analyses, and SP Swedish Testing and Research Institute for full-scale testing of wheels. Several visits to DB facilities in Germany were made. We were summoned to the concluding seven week criminal proceedings in January-February 2003 at the Regional Court of Lüneburg (held in Hannover). We then presented our findings by means of some 650 summarizing transparencies (data projections) in both English and German versions. In total, evidence had been taken from 93 witnesses and 16 experts since the lawsuit started on 28 August 2002. For a brief description of the accident, see Railway Gazette International, July 1998, page 449.

## Winter problems with wheels

Problems with damage to a large number of wheels on regional trains occurred in Sweden during winter 2001-2002. CHARMEC's Anders Ekberg, Elena Kabo and Roger Lundén have taken part in several meetings in Derby (UK) and Gävle, Stockholm, Surahammar and Västerås (Sweden) to clarify and remedy the situation. The program package FIERCE was applied, see under projects MU9 and EU6. The report below was compiled to facilitate the discussions. The problems were solved in the main by means of improved contact geometry (realized when turning the wheels), brake adjustment etc. New CHARMEC research aiming at alternative and improved wheel materials has later been started, see project MU16.

Anders Ekberg: Surface cracks in rolling contact – a brief review with focus on railway wheels, *Chalmers Applied Mechanics,* Gothenburg 2002, 14 pp

## ERWA

Ten wheelset manufacturers from eight European countries, including Lucchini Sweden, are members of the European Railway Wheels Association (ERWA). The objective of ERWA is to contribute to "improvements in wheels and wheelsets by focusing on safety, reliability and economic efficiency". Among the association's activities will be "the definition, adaptation and implementation of advanced technology". ERWA was launched during

the 13th Wheelset Congress in Rome in September 2001. Roger Lundén serves on ERWA's Technical Committee.

### New EU projects

Chalmers/CHARMEC have been invited to be a partner in several new EU projects on railway mechanics under the Sixth Framework Programme. We have taken part in general meetings in Brussels, Paris, Stockholm etc and also in the writing up of special applications. Among the proposed new projects is PERFORMINFRA focusing on higher axle loads and improved capacity of switches. This is a so-called Integrated Project (IP). In October 2003, we signed our contract as partner in a so-called Network of Excellence (NoE) named the European Rail Research Network of Excellence and abbreviated EUR²EX.

### 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 and labour unions. The chairman is Bengt K Å Johansson, former Swedish Government minister and later County Governor.

### IVA railway group

The Royal Swedish Academy for Engineering Sciences (Ingenjörsvetenskapsakademien, IVA) has started four groups for the discussion of industrial growth in today's "reregulated" society in Sweden. Among the issues treated are university research, knowledge dissemination, technology progress, entrepreneurial development and levels of governmental control. Roger Lundén is a member of the group concerned with railways. Its first meeting was held in Stockholm on 20 January 2003 and the group has since then met regularly. Chairman of the group is Staffan Håkansson, CEO of Bombardier Transportation Sweden.

### 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 doctoral candidates. Senior researchers have often been required at short notice to contribute in EU


Some of CHARMEC's co-workers in EU and other projects. From left: Martin Helgen, Markus Wallentin, Lennart Mähler, Jan Henrik Sällström and Hans Bjarnehed of Epsilon HighTech

and other projects. Chalmers/CHARMEC have consequently temporarily engaged the following, among others, as external consultants during Stage 3: Hans Bjarnehed, Lennart Mähler and Jan Henrik Sällström (all PhDs) and Martin Helgen and Markus Wallentin (both MScs) 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. The doctoral candidates Anders Johansson (TS5) and Tore Vernersson (SD4) are formally employees of Epsilon HighTech AB but work full-time at Chalmers Applied Mechanics. Dr Claes Fredö of Ingemansson Technology AB has contributed to a special project.

### Track switches

Two of the most recently launched CHARMEC projects are TS7 and MU14. The background is as follows. Banverket was the initiator and in collaboration with CHARMEC invited interested parties to a meeting in Stockholm for information exchange and brain-storming on 30 May 2000. Among the participants were the switch suppliers and constructors Cogifer Teijo in Finland, Cogifer Nordic in Örebro, Sweden, and the railway track-laying contractor Swedish Rail Systems (SRS), Ystad, Sweden. Cogifer is a French manufacturer and the company SRS installs switches from the Austrian manufacturer VAE. Further participants came from UIC in the UK and from Abetong Teknik, Inexa Profil and Duroc Rail in Sweden. Finally, researchers from the Swedish Transport and Communications Research Board (VTI) and from the technical

universities in Gothenburg, Linköping, Luleå and Stockholm took part.

A state-of-the-art study was initiated and jointly carried out by Banverket, CHARMEC and Epsilon HighTech Engineering with Jan Henrik Sällström as co-ordinator and editor, see under project TS7. A new meeting was held at Chalmers on 8 January 2002 with participation from the remaining interested parties Abetong Teknik, CHARMEC, Duroc Rail, Linköping University, SRS and VAE. This meeting was followed by a visit on 26-29 February 2002 to VAE in Zeltweg, Austria, by Roger Lundén, Jens Nielsen, Björn Paulsson and Bengt Åkesson, and by a visit on 2-3 May 2002 to voestalpine Schienen in Leoben, Austria, by Roger Lundén and Björn Paulsson. Preliminaries for collaboration between CHARMEC and the Austrian companies were discussed. In the meantime Jan Henrik Sällström took part in the International Railway Conference on Switches and Crossings at Delft, the Netherlands, on 19-20 March 2002.

The launching of the two projects TS7 and MU14 was approved by the CHARMEC Board on 6 March 2002 and the recruitment of doctoral students was started. Special financial support during the first three years of projects TS7 and MU14 was then granted by Banverket (totally KSEK 1050 + 1150 covering half the estimated project costs). For the period up to 30 June 2003, the projects had a direct contribution to their financing from VAE, see page 59. The joint reference group of projects TS7 and MU14 met at Chalmers on 25 February and 13 November 2003. Representatives from Banverket, Linköping University, Luleå Technical University, SL Infrateknik, VAE and voestalpine Schienen have participated. See further under the projects TS7 and MU14.

## Some visits abroad

Lennart Josefson and Jonas Ringsberg were invited to visit and lecture at Montanuniversität Leoben and voestalpine Schienen in Donawitz, Austria, on 31 January – 2 February 2001. Roger Lundén and Bengt Åkesson visited Austrak's sleeper factory in Rockhampton, Australia, on 18 June 2001 and lectured at City University in Hong Kong, China, on 26-28 June 2001. Jonas Ringsberg took part in a seminar with Banestyrelsen in Copenhagen, Denmark, on 30 August 2001. Lennart Josefson, Jonas Ringsberg and Jens Nielsen were invited to lecture at a seminar in Derby, UK, on 22 May 2001. On 10 September 2001, a prize for Best Paper was awarded at a ceremony and dinner at the headquarters of the Institution of Mechanical Engineers in London, UK, to CHARMEC's Magnus Ekh, Anders Johansson, Hans Thorberntsson and Lennart Josefson, see under project MU6 in CHARMEC's Triennial Report from Stage 2.

Torbjörn Ekevid and Nils-Erik Wiberg were invited to present a Keynote Lecture at the 5th WCCM Congress in Vienna, Austria, in July 2002, see under project VB5. Jonas Ringsberg was invited by the Transportation Research Board (TRB) in USA to give a seminar in Washington DC at TRB's annual meeting on 12-16 January 2003.

At the 2nd International Conference on Brakes and Wheels in Paris on 8-9 September 2003, Roger Lundén delivered a speech entitled "Synopsis of CM2003 Conference in Gothenburg".

## TRAINSAFE

This is a so-called thematic network funded by the European Union under its Fifth Framework Programme. The aim of TRAINSAFE is to "promote and enhance the safety of the rail system". CHARMEC's Lennart Josefson, Jens Nielsen and Jonas Ringsberg took part in TRAINSAFE's workshop "Safe Infrastructure" on 29-30 October 2003 in Leamington Spa, UK. A series of further workshops on different safety topics have preceded the present one and are planned up to June 2004.

## ERRAC and SRRA 2020

In September 2002, the European Rail Research Advisory Council (ERRAC) published a Strategic Rail Research Agenda 2020 (SRRA 2020). This document was discussed during the international evaluation of CHARMEC in March 2003, see page 11, and also during the visit to Gothenburg on 24 October 2003 by Antoine Mynard of ERRAC. According to ERRAC, rail research is required to develop Europe's railway business towards the objectives: a trebling of freight volumes and a doubling of passenger traffic by the year 2020.

ERRAC is an initiative of the European railway sector, the European Commission and the EU Member States. Individual members of the associations promoting the SRRA are UIC (International Union of Railways), UNIFE (Union of European Rail Industries), CER (Community of European Railways) and UITP (International Association of Public Transport Operators). It is said in SRRA that "Rail transport in Europe is a future oriented industry; its challenge is to offer a more efficient, attractive, affordable, safe, clean, competitive and reliable service".

# FINANCIAL REPORT

Here following are presented cash and in-kind investments for Stage 3 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 respective 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 main agreement 2000-06-22 with NUTEK (now VINNOVA).

## Report per party

Budgeted cash and in-kind investments per party according to the main agreement for Stage 3 are given in Table 1. Included are also the cash contribution KSEK 2735 (in addition to KSEK 5250, see below) from Banverket and the cash contribution KSEK 2250 from Chalmers, which were not stated in the main agreement.

*Cash investments*

In September/October/November 2000, agreements were reached between, on the one hand, each of Abetong Teknik AB, Adtranz Sweden (now Bombardier Transportation Sweden AB), Adtranz Wheelset (now Lucchini Sweden AB), Cardo Rail AB (now SAB WABCO Group AB), Duroc AB, Inexa Profil AB, SJ Cargo Group (now Green Cargo AB) and SJ Teknik (now TrainTech Engineering Sweden AB), respectively, and, on the other, Chalmers University of Technology AB on how the Industrial Inter-

*Table 1. Cash and in-kind contributions (KSEK) per party during Stage 3. The contributions for Inexa Profil, which was declared bankrupt on 2001-09-17 and later closed down, refer to year 1 of Stage 3*

| Party | Cash | | In-kind | | Total | |
|---|---|---|---|---|---|---|
| | Budget | Paid | Budget | Performed | Budget | Paid/Perf |
| VINNOVA | 18 000 | 18 000 | – | – | 18 000 | 18 000 |
| Chalmers | 2 250 | 2 250 | 18 150 | 18 150 | 20 400 | 20 400 |
| Abetong | 2 100 | 2 100 | 150 | 187 | 2 250 | 2 287 |
| Banverket | 7 985 | 7 985 | 1 500 | 969 | 9 485 | 8 954 |
| Bombardier | 3 000 | 3 000 | 1 500 | 1 517 | 4 500 | 4 517 |
| Duroc | 1 050 | 1 050 | 750 | 842 | 1 800 | 1 892 |
| Green Cargo | 1 440 | 1 440 | 0 | 0 | 1 440 | 1 440 |
| Inexa Profil | 250 | 250 | 250 | 173 | 500 | 423 |
| Lucchini | 3 000 | 3 000 | 2 400 | 2 918 | 5 400 | 5 918 |
| SAB WABCO | 1 500 | 1 500 | 900 | 449 | 2 400 | 1 949 |
| SL | 200 | 200 | 0 | 0 | 200 | 200 |
| TrainTech | 300 | 300 | 150 | 1 546 | 450 | 1 846 |
| From Stage 2 | 2 818 | 2 818 | – | – | 2 818 | 2 818 |
| TOTAL | 43 893 | 43 893 | 25 750 | 26 751 | 69 643 | 70 644 |

ests Group's payments to CHARMEC should be settled. According to these eight agreements, CHARMEC would invoice at the six points of time 2000-10-01, 2001-03-01, 2001-09-01, 2002-03-01, 2002-09-01 and 2003-03-01.

A corresponding agreement was reached in December 2000 between Banverket and Chalmers University of Technology AB in which Banverket's cash investment for the three-year period is KSEK 5250. According to this agreement, CHARMEC would invoice KSEK 875 at the six points of time specified above. In addition, Banverket would make an in-kind investment valued at KSEK 1500.

Another agreement was reached in March-April 2001 between Banverket and Chalmers/CHARMEC on the VB5 project "Wave propagation under high-speed trains" in which Banverket's cash contribution is KSEK 1365 during Stage 3 and KSEK 385 during the first part of Stage 4. According to the agreement, CHARMEC would invoice during Stage 3 at the five points of time 2001-05-01, 2001-09-01, 2002-03-01, 2002-09-01 and 2003-03-01. The amounts are KSEK 227.5 on 2001-05-01 and 2001-09-01, KSEK 262.5 on 2002-03-01 and 2002-09-01, and KSEK 385 on 2003-03-01. An agreement to invoice KSEK 220 on 2000-09-01 had already been reached during Stage 2.

During the spring 2002, Banverket decided to contribute, in addition to the above, 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. Further, during the autumn 2002, Banverket decided to contribute to the project SP7 "Lateral track stability" KSEK 300 + KSEK 365 during Stages 3 and 4, respectively. The amounts KSEK 450 + KSEK 400 + KSEK 300 for Stage 3 are included in the budget shown in Table 1.

Chalmers University of Technology also supports its competence centres financially. During Stage 3, the sum of KSEK 2250 was allocated for CHARMEC.

An agreement was reached in January 2003 between SL Infrateknik AB and Chalmers University of Technol-

*Table 2. Budgeted and used cash and in-kind contributions (KSEK) during Stage 3, with Industrial Interests Group (including Banverket) and Chalmers shown separately, for each programme area and for management and administration. CHARMEC's programme areas for Stage 2 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 | 9 150 | 9 919 | 1 250 | 2 049 | 2 650 | 2 650 | 13 050 | 14 618 |
| VB | 6 660 | 6 350 | 2 000 | 2 432 | 2 250 | 2 250 | 10 910 | 11 032 |
| MU | 12 975 | 13 947 | 2 450 | 2 240 | 6 300 | 6 300 | 21 725 | 22 487 |
| SD | 5 825 | 4 553 | 1 900 | 1 880 | 2 550 | 2 550 | 10 275 | 8 983 |
| EU | 3 500 | 3 500 | – | – | 1 500 | 1 500 | 5 000 | 5 000 |
| SP | 935 | 600 | – | – | – | – | 935 | 600 |
| Management | 4 400 | 4 639 | – | – | 2 900 | 2 900 | 7 300 | 7 539 |
| TOTAL | 43 445 | 43 508 | 7 600 | 8 601 | 18 150 | 18 150 | 69 195 | 70 259 |

*Note 1* The costs corresponding to the cash contributions 2 × KEUR 45 from VAE AG and voestalpine Schienen GmbH (see page 59) are KSEK 250 (TS) + KSEK 550 (MU). These costs are not included in Table 2 (under Cash, Used)

*Note 2* Management also includes KSEK 200 to support the conference CM2003, see page 62

*Note 3* The balance in cash to be transferred to CHARMEC's Stage 4 by 2003-06-30, including the interest paid in, is KSEK 43,893 + 207 – 43,445 = 655

ogy AB under which SL Infrateknik, as a new member of the Industrial Interests Group, contributes a cash investment of KSEK 200 for the period 2003-01-01 – 2003-06-30. The agreement was written for three years but has later been replaced by the main agreement for Stage 4 from 2003-07-01.

With the exception of Inexa Profil, all amounts due for CHARMEC's Stage 3 have been received as per the agreements, as follows (KSEK)

| | |
|---|---|
| 6 × 350 | from Abetong Teknik |
| 6 × 875 + 2 × 227.5 + 2 × 262.5 + 385 + 220 + 450 + 400 + 300 | from Banverket |
| 6 × 500 | from Bombardier Transportation Sweden |
| 6 × 175 | from Duroc |
| 6 × 240 | from Green Cargo |
| 2 × 125 | from Inexa Profil |
| 6 × 500 | from Lucchini Sweden |
| 6 × 250 | from SAB WABCO Group |
| 1 × 200 | from SL Infrateknik |
| 6 × 50 | from TrainTech Engineering Sweden |

Also received quarterly is the following (KSEK)

| | |
|---|---|
| 12 × 1500 | from VINNOVA |

Finally, KSEK 2250 has been received from Chalmers. 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 3, 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 of 1995-11-07 were enclosed with the form. On the form were shown salary costs (number of hours and cost per hour) and other costs (use of machines, materials and computers, travel expenses, services purchased etc). 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 – 2003-06-30 (– 2006-06-30) |
| *Chalmers budget (excluding university basic resources)* | Stage 1: KSEK 1084<br>Stage 2: KSEK 4000<br>Stage 3: KSEK 4200+200<br>Stage 4: KSEK 3600 |
| *Industrial interests in-kind budget* | – |

Roger Lundén has devoted about half of his full-time position to the management and administration of the CHARMEC Competence Centre during its Stage 3, the rest of his time being given to his duties as teacher, researcher and research supervisor in Solid Mechanics/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 Solid Mechanics/Applied Mechanics. She has also served as the Centre's secretary. For Stages 3 and 4, Dr Anders Ekberg has joined Bengt Åkesson and Birgitta Johanson in the administration of the Centre. All three participate on a part-time basis.

## CHARMEC STAGE 4

An agreement on CHARMEC's Stage 4 (1 July 2003 – 30 June 2005/30 June 2006) was made at VINNOVA's office in Stockholm on 19 June 2003. In addition to the previous eight members (including SL Infrateknik) at the end of Stage 3, the new member voestalpine Bahnsysteme then joined the Industrial Interests Group. In the same way as for Stages 1, 2 and 3, a separate agreement has been drawn up for Banverket's participation. The programme areas during Stage 4 are the same as during Stage 3, see TS, VB, MU, SD, EU and SP on page 10.

The funding (kSEK) of CHARMEC's Stage 4 is shown in the table below. The payment from Brussels of the projects EU6, EU7 and EU8 is not included in the table. As of 1 January 2001, the new national research agency VINNOVA has taken over NUTEK's responsibility for CHARMEC.

Jan-Eric Sundgren, President of Chalmers University of Technology, has appointed the following as members of the Board of CHARMEC during Stage 4 (decision dated 2003-08-19):

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

For photo of the new Board, see page 9

| | Cash | In-kind | Total | Year 1+2 |
|---|---|---|---|---|
| VINNOVA | 12 000 | – | 12 000 | 30 % |
| Industrial Interests Group | 13 320 | 9 030 | 22 350 | 37 % |
| Chalmers | 1 500 | 18 000 | 19 500 | 33 % |
| Banverket | 7 506 | 1 350 | 8 856 | |
| From Stage 3 | 655 | – | 655 | |
| TOTAL | 34 981 | 28 380 | 63 361 | 100 % |

VINNOVA VERKET FÖR INNOVATIONSSYSTEM the Swedish Agency for Innovation Systems, became operational on 1 January 2001. Among VINNOVA's main roles are to finance research, development and demonstration activities that meet the needs of business and the public sector, and to foster co-operation between universities, industrial research institutes and business.

## CONCLUDING REMARKS

As evident from the international evaluation in March 2003 (see the Executive Summary on page 6), Stage 3 of the NUTEK/VINNOVA Competence Centre in Railway Mechanics has been successful. Co-operation between the University and the Industry has been developed and the national and international network has been widened. In my opinion, CHARMEC has further established itself, nationally and internationally, as a supplier of first-rate research, as a knowledgeable partner for dialogue, as an important information hub, and as a competent network builder. I look forward to the Centre's Stage 4 with confidence.

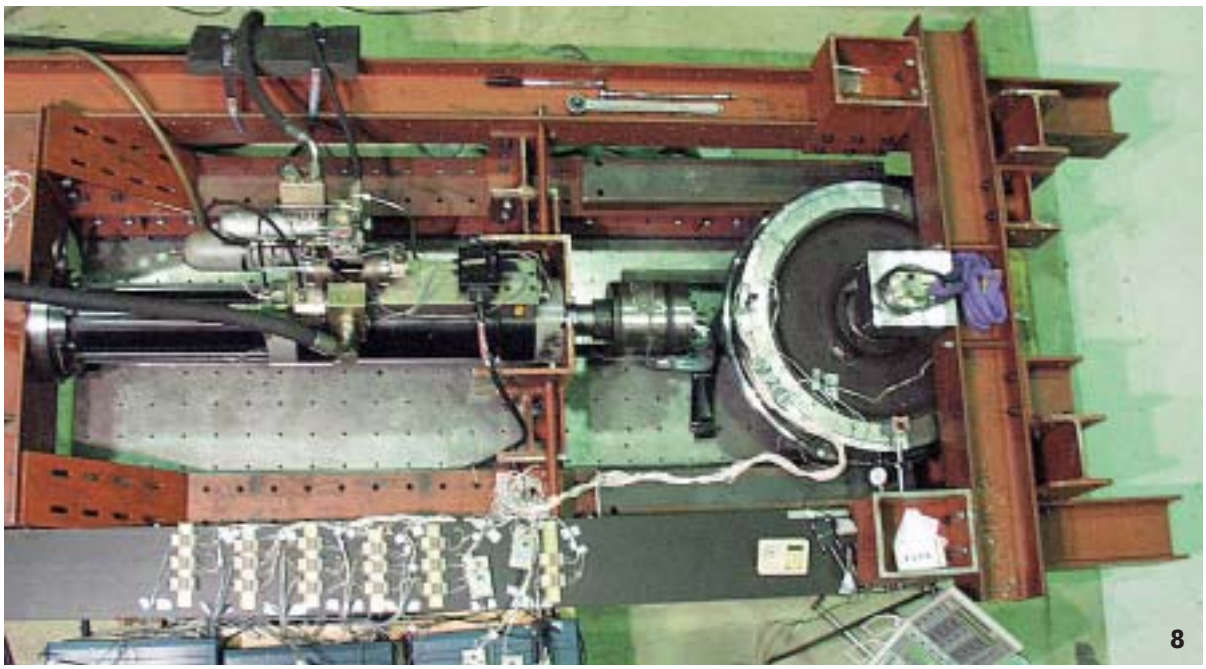
Since Railway Mechanics will continue to be a key area for the development of sustainable ground transportation, it is of great importance that the continued existence and stability of CHARMEC can be secured even after Stage 4.

*Gothenburg in December 2003*

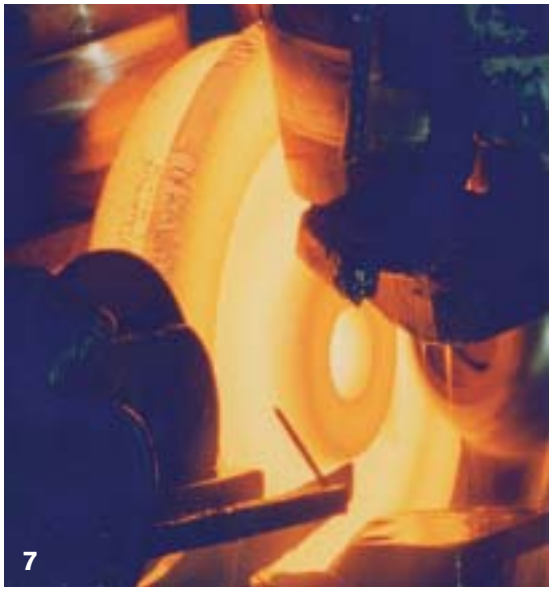
ROGER LUNDÉN

Photo: Bo Håkansson, Kamerareportage

1. TrainTech Sweden's instrumented wheel for measuring contact forces wheel/rail
2. SL metro trains of type C20 on the Söderström bridge in Stockholm
3. Iron Ore Line in Sweden upgraded by Banverket to 30 tonne axle load
4. Rails from voestalpine's rolling mill in Leoben/Donawitz
5. Ventilated axle-mounted brake discs from SAB WABCO








6. Reprofiling a wheelset in the Duroc maintenance shop at Notviken (Luleå)
7. Rolling of a forged Lucchini wheel
8. German BA64 wheel at SP Swedish Testing and Research Institute
9. Main-line and turnout sleepers manufactured by Abetong Teknik
10. Green Cargo's standard freight wagon of H type
11. Bombardier's interregional train Regina

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# CHARMEC

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**Mechanics**

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