THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

In

SOLID AND STRUCTURAL MECHANICS

Towards Optimization of Railway Turnouts

BJÖRN PÅLSSON

Department of Applied Mechanics
Chalmers University of Technology
Göteborg, Sweden 2011

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BJÖRN PÅLSSON

Thesis for Licentiate Engineering 2011:02
ISSN 1652-8565

Department of Applied Mechanics
Chalmers University of Technology
SE-412 96 Göteborg
Sweden
+46 (0)31-772 10 00

Cover:
Simulated and then discretized contact point trajectories for a regular (circles) and a hollow worn (squares) wheel profile during a crossing transition

Chalmers Reproservice
Göteborg, Sweden 2011

BJÖRN PÅLSSON
Department of Applied Mechanics
Chalmers University of Technology, SE-412 96, Göteborg, Sweden
E-mail: bjorn.palsson@chalmers.se, Phone: +46-(0)31-772 1491

Abstract

The turnout (Switch & Crossing) is a vital component in railway networks as it provides flexibility to traffic operation by allowing trains to switch between tracks. The flexibility comes at a cost as the common lack of a transition curve in the diverging route together with the variation and discontinuities in rail profiles result in higher rail degradation rates than in regular track. In this thesis, dynamic interaction between vehicle and turnout is studied using numerical tools for multibody dynamics with focus on laying a foundation for robust optimization of turnout geometry.

Considering a stochastic spread in traffic parameters, quantitative and qualitative estimates of rail profile degradation are computed. The influence of wheel profile wear on wheel–rail interaction in a turnout is studied, and it is concluded that equivalent conicity is the wheel profile characterization parameter with the best correlation to rail damage of the investigated parameters. In addition, the influence of hollow worn wheels on rail damage is investigated and it is found that such wheel profiles display a significantly different and potentially more harmful running behaviour at the crossing. The influence of wheel–rail friction coefficient is studied and it is shown that friction correlates strongly to lateral contact forces and wear in the diverging route. Wheelset steering, considering the turnout specific configuration of rail profiles and the presence of check rails, is discussed. One of the track models studied is a discretized mass-spring-damper model with nine degrees-of-freedom. This track model can be tuned to capture the large phase delay at low frequencies found in measurements of dynamic track stiffness, while remaining sufficiently resilient at higher frequencies. Good agreement between the simulation model and field measurement data has been observed. It is concluded that the use of more resilient rail pads can reduce wheel–rail impact loads during the crossing transition.

Keywords: dynamic vehicle–track interaction, turnout, switch & crossing, wheel and rail wear

Preface

The work presented in this thesis has been carried out from September 2008 to March 2011 in the Department of Applied Mechanics at Chalmers University of Technology within the project TS13 “Optimization of Track Switches”. This project forms part of the activities in the Swedish National Competence Centre CHARMEC (CHAlmers Railway MEChanics) with special support from voestalpine Bahnsysteme, Trafikverket and SL Technology.

There are a number of persons who directly or indirectly have contributed to this thesis. First and foremost I would like to express my gratitude towards my supervisor Professor Jens Nielsen whose enthusiasm and seemingly infinite patience in improving my manuscripts have been invaluable for the completion of the thesis. I would like to thank Professor Roger Lundén for employing me and for providing the inspirational research environment that is CHARMEC, although I sometimes think I was offered the job partly due to my name. Credit is also given to my assistant supervisor Professor Thomas Abrahamsson.

I would also like to thank the members of the TS13 reference group; Heinz Ossberger and Erich Scheschy of VAE GmbH, Jan-Erik Meyer and Ralf Krüger of Trafikverket, Mounir Ainholm of SL and Professor Igor Rychlik of Chalmers for their guidance and questions. Dr Arne Nissen, Trafikverket, coordinated the INNOTRACK Eslöv field measurements that have given me a lot of good data to work with. Ingemar Persson, DEsolver AB, has provided generous and patient support with GENSYS modelling and simulation. Dr Elias Kassa allowed me to get a flying start in TS13 due to his previous efforts in the CHARMEC project TS7. Thanks also to my colleagues on the third floor (including those who still haven’t confessed to the dots) for providing a pleasant working environment.

To my mother and father who have always believed in me, and my sisters who have to live with yet another engineer in the family.

Göteborg, March 2011

Björn Pålsson

Thesis Content

This thesis consists of an extended summary and the following appended papers:

Paper A
A Johansson, B Pålsson, M Ekh, J C O Nielsen, M K A Ander, J Brouzoulis, E Kassa, Simulation of wheel–rail contact and damage in switches & crossings, *Wear*, 2010, doi:10.1016/j.wear.2010.10.014

Paper B
B Pålsson, J C O Nielsen, Wheel–rail interaction and damage in switches and crossings. Accepted for publication in *Vehicle System Dynamics*

Paper C
B Pålsson, J C O Nielsen, Track model validation for simulation of train–turnout dynamics. To be submitted for international publication

The appended papers were prepared in collaboration with co-authors. The author of this thesis is responsible for the major progress of the work in preparing papers B and C. This includes taking part in the planning of the papers, carrying out the modelling and numerical simulations and writing the report. The author was present during the field measurements reported in paper C, but the tests were coordinated and performed by Trafikverket and subcontractors. In paper A, the author planned and carried out the simulations of vehicle–turnout interaction, and performed most of the corresponding writing.

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Paper A - Simulation of wheel–rail contact and damage in switches & crossings
Paper B - Wheel–rail interaction and damage in switches and crossings
Paper C - Track model validation for simulation of train–turnout dynamics

1. Introduction

The work in the present thesis is an effort towards optimization of railway turnouts (Switches & Crossings, S&C) using MultiBody Simulation (MBS) tools. The end objective is to reduce the dynamic contribution to wheel–rail contact forces, minimize rail degradation due to dynamic train–turnout interaction, and in the long run reduce the Life Cycle Cost (LCC) for turnouts.

The topics investigated are the influence of the stochastic spread in traffic parameters (vehicle types and speeds, axle loads, wheel profiles, wheel–rail friction coefficient, etc) on the loading and degradation in a turnout, and the comparison of simulation results to measurement data to evaluate and validate the accuracy of the simulation model. The intention is that the knowledge gained in this work will provide a foundation for the optimization and development of a more robust and applicable turnout design. The author also hopes that the present thesis will highlight and aid the understanding of the kinematical challenges associated with turnout design. This work is as an extension of the work performed by Elias Kassa within the previous CHARMEC project TS7 [1].

2. The Turnout

The role of the turnout is to provide flexibility to railway traffic operation by allowing trains to switch between tracks. There are many different turnout configurations [2] to fulfil the needs of varying traffic demands. Figure 1 illustrates a common turnout layout which is studied in the present project. It features a straight section called the through route and a curved deviating part called the diverging route. The front of the turnout is defined as the start of the deviating curve in the switch panel. The switching function is realised by switching machines or actuators that position the switch rails according to the desired traffic route. The closure panel connects the switch and crossing panels, where the crossing allows for wheels to travel along both intersecting paths. Opposite to the crossing and next to the adjacent through (stock) rails, are the check rails that enforce a constraint on the lateral position of passing wheelsets. This is to avoid that wheels hit the tip of the crossing nose which might cause severe damage and derailment.

The variations and discontinuities in rail profiles, present in the turnout to achieve the function of the switch and crossing, result in an increased dynamic loading during wheel passage and thus increased wear and tear on these components compared to common track. Wear and accumulated plastic deformation and Rolling Contact Fatigue (RCF) are common damage mechanisms in the switch and crossing panels [3]. Further, turnouts are often built without transition curves, causing large vehicle jerk at entry and exit of the diverging route. Due to the planar nature of a turnout, track inclination to compensate for the lateral acceleration is not possible.

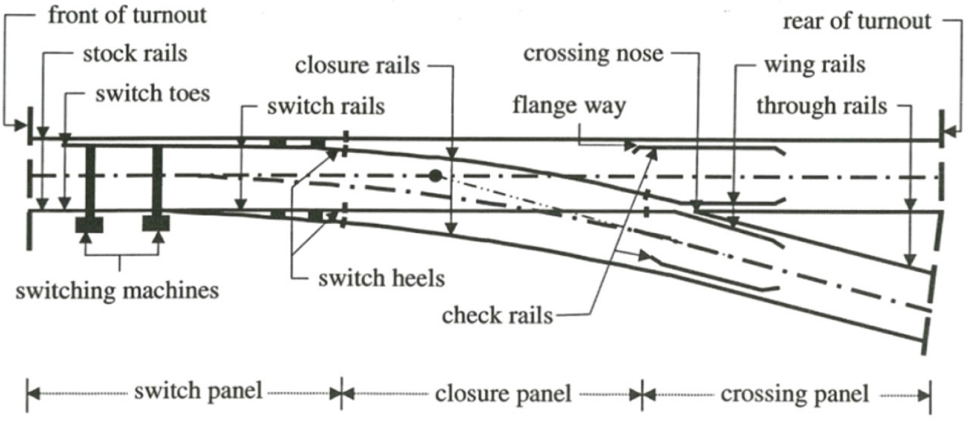

Figure 1. Schematic illustration of a turnout and its components

3. Motivation of Work

The simple fact that railway systems are a vital part of the transport infrastructure all over the world, consuming large capital resources for their construction and maintenance, motivates targeted research with the aim to increase the value for the money spent. Turnouts stand for a considerable contribution to reported track faults. Only in Sweden there are over 12 000 turnouts in its some 17 000 km of track, and the cost for turnout operation and maintenance was 250-300 MSEK per year 2001-2004 [4].

4. Objective

In an industrial setting, optimization often means an activity that aims to reduce the LCC of a product or system. As the turnout function is built from many constituents, there are several areas where improvements can be sought for, for example ground and track stability, material selection and general geometric design. This work is focused on the understanding of dynamic wheel–rail interaction in turnouts, and how the rail degradation can be reduced by changes in geometrical and flexibility properties of the superstructure like rail profile, track gauge and rail pad stiffness. It is not necessarily the case that an optimized geometry fresh from the computer leads to lower LCC for the realized turnout, as it, for example, might be more expensive to manufacture. It is however hard to imagine an optimization set-up where all LCC-affecting parameters of the turnout are considered at once. Therefore the efforts of TS13 can in a sense be regarded as being part of a multidisciplinary optimization where problems in vehicle–turnout interaction can be identified and pondered on. Then suggestions for improvements can be fed into the turnout design and manufacturing community for evaluation against the global objectives of minimized LCC and compliance to regulations and other requirements.

5. Method in Short

The tool chosen for the investigation of vehicle dynamics is numerical multibody simulations as it is a computationally efficient method to obtain relatively accurate results for the dynamic interaction in a train–turnout system including the kinematics of the interacting parts and the corresponding interaction forces. The project aims to reduce the degradation of turnout rails, but it should be remembered that quantitative estimates of rail degradation is a very complex task that requires very large computing power. Therefore, in an optimization where a computationally inexpensive evaluation of the objective function is vital, the damage estimates have to be formulated in more qualitative terms using wheel–rail interaction quantities like force, creep and pressure. Examples of such criteria are maximum normal contact force, wear index $T\gamma$ [5] or criteria for RCF [6]. The MBS simulations have been performed with the commercial code GENSYS [7], using a model of a freight train featuring Y25 bogies that was developed in [8].

6. Related Work

The area of simulation-based investigations of train–turnout interaction is a field that does not contain that many flowers but has become more populated in recent years. As the field of railway mechanics is huge and optimization of train–turnout interaction is related to many aspects of it, this section will focus on papers where work similar to that in the current thesis has been presented. For an introduction into the general considerations of simulation of train–turnout interaction, covering vehicle, track and contact modelling, see [1].

In [9], the influence of track stiffness on the wheel–rail impact load at the crossing nose is studied using a two-dimensional MBS model. It was found that the impact load can be significantly reduced by introducing a more resilient track structure. Similar results are reported in [10], [11] and in **Paper C** of this thesis. Reference [10] also includes studies of different crossing geometries. Simulations of the contact force time history at the train's passing of a turnout are presented in [12] and [13]. **Paper C** features a comparison of measured and calculated wheel–rail contact forces, which also was the topic in [14]. As the two turnouts investigated in [14] and **Paper C** were of a similar type, it is pleasant to note that the measured wheel–rail contact forces are very similar. The rail wear in a turnout switch is the particular focus in [12], where similar levels of the wear number $T\gamma$ are presented as in **Paper B**. By linking MBS simulations to detailed contact modelling and calculations of plastic deformation and wear, a methodology for the prediction of rail degradation considering spread in traffic parameters is presented in **Paper A** and [16]. On a more global scale, so-called kinematic gauge optimization has been studied in [17],[18] and [19], where the latter reference also covers the optimization of track curvature. Kinematic gauge optimization aims to compensate for the asymmetry in rail profiles that causes lateral wheelset movement when a vehicle passes through the switch in the through route, which might cause flange contact on the switch rail. Stochastic analysis of train–turnout interaction in a switch is discussed in [20] and is related to **Paper B**.

7. Future Plans

The plan for the author's upcoming work is to perform a numerical optimization of the turnout. The objective is to minimize rail degradation using parameters affecting the vehicle dynamics in the turnout, such as track gauge, rail profile and check rail geometry, as design variables. In the formulation of the objective function(s), the stochastic spread in traffic parameters as covered in **Paper B** will be considered and the knowledge of the required detail of track model gained in **Paper C** will be utilized. Further, efforts will be made to consider the long-term performance and stability of the optimized geometry.

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