20th Nordic Seminar on Railway Technology

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Abstracts



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Prevention and mitigation of derailments – a new IRS

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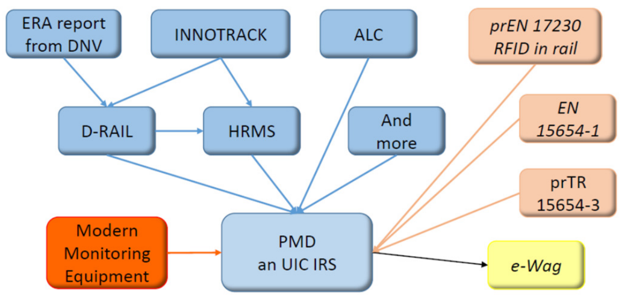
Foreword

The two most important challenges in strengthening the competitiveness of rail freight are to reduce costs and increase reliability. To obtain these aims, there are several recent and on-going research and development projects. Sadly, too few have been implemented in real use. Also new standards are recently being approved and the development of monitoring equipment during recent years have made them more reliable with better accuracy and cheaper. For these reasons this International Railway Solution (IRS) under the name "Prevention and Mitigation of Derailments" (PMD) is produced.



Focus areas to prevent derailment

In short, the objectives of the standard are to prevent the number of derailments and also to reduce the impact of occurring derailments by mitigation measures. This can be done by using wayside track monitoring equipment in a manner that is more cost-efficient. In the IRS it is described how current and future demands on reliability and accuracy on monitoring equipment shall be taken into account. There are also recommendation how to measure track forces and recommendation for calibration. Also track forces and limit values are recommended for vertical axle loads together with values for load distribution. To make this possible it is important to identify malfunctioning wagons earlier by identification. This is done by using RFID and how to place it on the vehicles.

Conclusions

- It emphasises the importance to use measuring sites with equipment that have good accuracy and are calibrated regularly
- Recommendations using harmonised warning and alarm limits in order to reduce derailment and promote cross border traffic
- Railway vehicles must be RFID tagged to allow identification.

References

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Maintenance strategies for advanced rail damage mitigation

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Introduction

Rail surface and profile rectification is a well established process in modern rail asset management that has proven worldwide to extend the life of rails and wheels in different railway systems. Most commonly, rail grinding is used to manage rail degradation by applying different strategies such as preventive or cyclic maintenance. However, operational or external factors beyond control can interfere with such strategies. This may cause the rail to degrade beyond a level that cannot be easily managed with grinding. For such corrective measures, a technology is required that can reliably and efficiently restore the rail condition to a manageable level (corrective maintenance) – Schoech (2017).

Curative Maintenance

Curative maintenance does not only restore the rail condition to a manageable level (as with corrective maintenance) but completely "cures" the rail surface to a damage free, as-new condition. Rail milling is a rotary cutting process that is capable of substantial metal removal (in one pass) as required for a curative (and also corrective) maintenance strategy.

Milling Technology Analysis

Based on a collaboration between LINMAG, Materials Center Leoben (MCL) and the chair of mechanics at the University of Leoben in Austria, the milling process will be discussed in detail. Process simulation and examination are included to show the impact of the process on the rail material – Kubin (2017). The results obtained will also be compared to similar investigations done with respect to conventional rail grinding to highlight the significant characteristics of both processes. Additionally, specific examples of milling applications at different railway systems will be explained and analysed to highlight how milling can be efficiently used to restore damaged rail to its initial condition.

Conclusions

By combining rail grinding strategies (preventive approach) with the complementary rail milling technology (curative and corrective approach) it is possible to create an innovative rail management solution that will maximize rail life while at the same time minimizing operational and maintenance costs.

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Schoech, W., "Preventative rail maintenance by grinding – exploring the limits", In Proc. of the 11th International Heavy Haul Association Conference, Cape Town, pp.121-128, 2017
Kubin, W. et al., "Finite Element Analysis of rail milling as rail maintenance process", In Proc. of Railway Engineering 2017 Conference, Edinburgh, Scotland, 11 pp. 2017

Railway wheels and tread brakes

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Railway wheels are key components when it comes to basic functioning, reliability and safety of railways. They have fundamental functions in the system through their transfer of vertical, lateral and longitudinal forces between the vehicle and the rail and by providing running stability by means of the conicity of the tread. Further, wheels make tread braking possible and act as a heat sink. However, they constitute a large part of the vehicle maintenance expenditures and contribute to noise emission of railways.

Railway wheel technology is continuously developing due to the ever increasing axle loads, train speeds and requirements on low maintenance costs and reduced noise emissions. Presently, there is a demand for a better understanding of degradation and limiting phenomena of the wheels, e g, related to braking. An overview of wheel types will be given in which basic functions and solutions are discussed. Some relevant research and evolving topics that perhaps are not generally known but are important for proper functioning of the wheels are highlighted. The presentation builds on our work with wheel related issues over more than 30 years.

For tread braked wheels, wheel design and functioning are complex issues since at braking the kinetic energy the train is transformed into heat, of which a major part is transferred to the wheels. The resulting elevated temperatures combined with mechanical loading make braking a complex system issue. Recent research findings are presented where limiting temperatures of the tread are established based on an analysis of the thermal impact on rolling contact fatigue. Here a combined experimental and numerical study, involving tests in a non-standard brake rig at the Railway Technical Research Institute in Tokyo, has been combined with material testing and numerical simulations at CHARMEC. Material behaviour for temperatures up to 600 ^{o}C are found in the experiments and are considered in the simulations.

In addition, over the last decades, there has been a strong drive in the society and the railway industry to reduce rolling noise. This means that the traditionally used cast iron brake blocks are being replaced by “silent” brake blocks made from organic composites and sinter materials. For this purpose LL-type brake blocks have been developed for usage as retro-fit solutions to cast iron blocks, mimicking their frictional behaviour, but reducing their propensity to cause wheel tread roughness. The introduction of this new block type has, however, introduced some unwanted phenomena, such as increased tread wear and unreliable braking performance at winter conditions. Information relating to block wear and tread wear are presented and the main differences between LL-blocks and cast iron blocks are highlighted. Also results pertaining to simulations of natural de-icing of brake blocks and holders for different types of brake block materials for drag braking conditions are presented. The results indicate that the low thermal conductivity of organic composites may be a main reason for the build-up of ice at tread braking with such brake block materials.

Investigation of material properties of the surface layer of rails

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Large shear strains typically develop in the near-surface region under the running band of railway rails (Figure 1). Rolling Contact Fatigue (RCF) cracks often initiate in this region, causing major problems for the railway industry. However, characterization of the constitutive and fatigue behavior of this region is difficult due to the large gradient of properties. In the present work, the deformed microstructure in this region is characterized. An axial-torsion test rig is used to predeform cylindrical low-cycle fatigue specimens in order to obtain material properties similar to those of the near-surface region in rails. These specimens are more suitable for further mechanical testing, compared to those resulting from many of the other predeformation methods described in the literature. The obtained material is compared to field samples in terms of the material hardness and microstructure. The microstructure is evaluated with both optical microscopy and scanning electron microscopy. This comparison shows that the predeformed material state closely resembles what is found in some used rails at a depth between 50 and 100 μm.

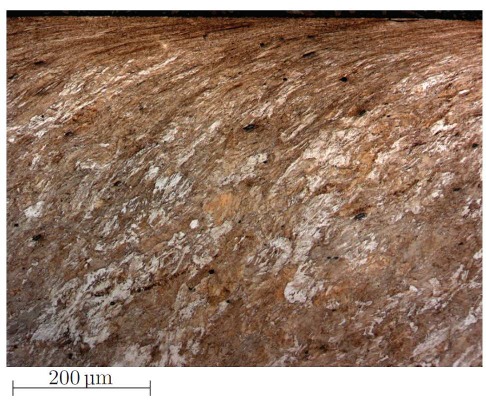

Figure 1 Deformed surface layer of a rail from Meyer et al. 2018

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The influence of high strength rails on running behaviour and wheel wear

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Introduction

The service life of rails and wheels is limited by the formation of rolling contact fatigue defects (RCF), wear and corrugation. Various investigations have proven that rail steels with optimized microstructure to achieve maximum wear and RCF resistance are beneficial for both sides of the rail/wheel contact and are able to decrease the total system wear. The presentation illustrates the underlying mechanisms for this phenomenon, focusing especially on wheel-rail-contact-geometry

Analysis

The present investigation is aiming for revealing the phenomena behind track observations and several test rig results:

- How do rail steels with high wear resistance influence the wheel rail contact geometry?
- Which influence on wheel-rail-contact forces can be expected due to the profile development of different rail steels?

The development of wear profiles is evaluated from long-time real track measurements for various state of the art rail steels by cross-section-measurements. Multi body simulations are used to analyse contact forces and wear parameters for the profiles that have developed in track for different rail steels.

Conclusions

Based on the findings of on-site evaluation, the positive effect of hypereutectoid rail steels on the profile stability is demonstrated. This means that a highly wear resistant rail will keep its design profile for longer time with less need for rail maintenance. Especially in tight curves, parameters determining the wheel wear are positively influenced to a great extent by profile stability, resulting in a reduction of forces and stresses in wheel-rail-contact.

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Modelling of thermomechanically loaded rail and wheel pearlitic steels

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Introduction

Fatigue failures due to thermomechanical damage are reasons for premature railway rail and wheel removal, major cost factors and safety issues for operations of railroads. Hence, it is desirable to investigate thermomechanical damage mechanisms and develop a method for prediction of failures in the rail and wheel materials.

This contribution consists of two studies. In the first study [1], the influence of different conditions (e.g. initial speed of train and brake block material), during block (tread) braking, on the mechanical behavior of wheel tread pearlitic steel is investigated. In this situation, the wheel material is subjected to simultaneous mechanical (cyclic multiaxial stresses) and thermal loads (temperatures up to 500 ℃) due to rolling contact and stop braking, respectively. A methodology for finite element (FE) simulation of the tread braking, accounting for a viscoplastic material model and accurate thermal and contact analysis, is developed. The methodology also incorporates prediction of the rolling contact fatigue life of the material. The methodology aims at reproducing full-scale block brake rig experiments.

In the second part of the study, the thermal damage mechanisms caused by short-term local friction heating on pearlitic rail and wheel steels are investigated [2]. This type of loading might result into initiation of cracks, specifically squats (studs) in rails and crack clusters in wheels. Short term local friction heating in railway operation might occur when a railway vehicle's wheelset skids along the rail. The consequent temperature elevation (usually 800-1000 ℃) in the rail and wheel steels results in phase transformations. The temperature dependent differences in thermal expansion, density and mechanical properties of phases result in residual stresses which can cause thermal damage mechanisms in rail and wheel steels.

Conclusions

In the first study, it is found that for similar axle loads, the wheel tread fatigue life is highly influenced by the choice of brake block material. Between the two types of studied brake block materials (sintered and organic composite), the composite blocks result in lower peak temperatures in the tread and consequently a substantial increase in the predicted fatigue life.

In the second study, loading cases similar to what is expected during wheel's skidding along the rail is considered. The simulations of the thermal field and phase transformations show a development of substantial residual stresses below the rail-wheel contact surface.

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A new measurement method to determine structural parameters of a railway track

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Abstract

Evaluation of track properties are made possible by measurement of longitudinal level in a plurality of positions at different distances from a bogie in the measurement car IMV200. After eliminating the longitudinal level, the effect from wheel loading remains in the measurement data. The measurements are compared with a track model, where the parameters of the model (describing track properties/structural parameters) are varied such that a best possible match with measurements is achieved. The procedure is repeated along the track allowing track properties to be estimated for long distances.

Models of various complexity can be used for estimating different parameters. Track stiffness is the parameter influencing deflection shape the most and is always included. A great challenge is to also include longitudinal forces of the rail in order to estimate the stress-free temperature of the rail with the same methodology.

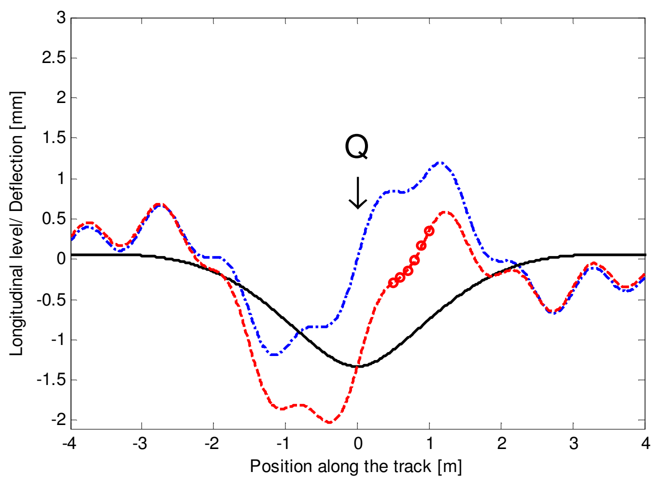

Figure 1 Principle of track stiffness measurement. Blue dash-dotted line: longitudinal level without wheel load, red dashed line: longitudinal level with wheel load, black solid line: rail deflection due to wheel load, red circles: positions of measurements.

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Track geometry degradation on Malmbanan – correlation between support stiffness gradient and differential settlement

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Degradation of longitudinal level due to traffic loading generates a need for maintenance (tamping) as the level of track irregularities is approaching the acceptance limit. An important contribution to such degradation is differential track settlement induced by dynamic vehicle–track loading and variations in support conditions along the track. Poor quality in track geometry leads to higher dynamic wheel–rail contact forces and increases the degradation rates resulting in further track settlement, and possibly to increased wear, plastic deformation and rolling contact fatigue of the rails.

Traffic on Malmbanan is dominated by iron ore freight trains with axle loads 30 tonnes. Since 1997, track geometry data is available in digital format enabling detailed studies of degradation over the last 20 years. The recorded longitudinal level is a combination of the unloaded track irregularity (mainly due to variations in horizontal level of the original ballast surface and subsequent differential settlement) and the displacement of the loaded rail, which is space-variant due to irregularities in the vertical support stiffness. Recently, simultaneous measurement of longitudinal level and track stiffness has been made possible based on updates of the standard measurement system.

The objective of the presentation is to demonstrate an enhanced method for the characterisation of railway track and detection of track sections with poor support conditions. Long-term track geometry degradation on Malmbanan is assessed. Simultaneous and synchronised measurements of longitudinal level and track stiffness are evaluated. The results show significant influences of seasonal variations and track stiffness gradients on long-term differential settlement.

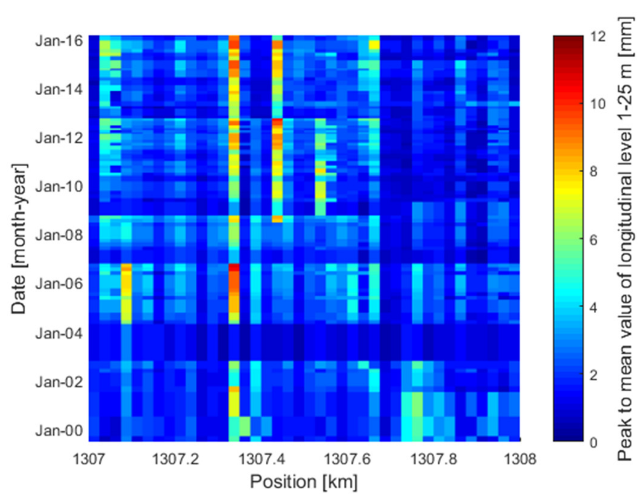

Figure 1 Example of track geometry degradtion evaluated over 20 years

Measurements of contact pressure between sleeper and ballast

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The contact pressure between sleeper and ballast at train passage is measured on four different sleepers in Lerum, Sweden. Two of the sleepers have Under Sleeper Pads (USP) and two do not. The measurements are done by using a thin film that measures both static and dynamic loads. The film is placed between sleeper and ballast and connected to a computer where the applied software visualizes the pressure when trains are passing. The equipment has not been used in this context before and it will therefore be verified if it is suitable for this type of testing also continuously.

Distribution of contact pressure is one of the most important factors when designing sleepers. The exact in situ distribution is unknown and will vary from one sleeper to the next. This measurement technology can provide information to be used for optimization of sleepers and to evaluate the performance of tamping technology. Further, knowledge about the influence of USP can provide input to decide when these should be applied.

The results are realistic in terms of pressure distribution and magnitude, which makes the equipment suitable for future testing. However, the bending moments are higher than what would be expected. The reason is most likely that the film, with two layers of protecting rubber, increases the height of the sleeper which introduces an error in track geometry

Contact pressure was lower at the sleeper centre than at the rail seats. Three of the four sleepers were subjected to a non-symmetric load with a higher load at the right rail seat. Further, it was found that three of the sleepers were subjected to a higher load along one of long sides. This indicates that the ballast pressure distribution was not fully according to the regulation of the UIC code [1]. The reason for the uneven distribution of contact pressure could be due to an error in the execution of tamping the ballast at track renewal, a non-symmetric irregularity in longitudinal level, and/or the direction of the traffic.

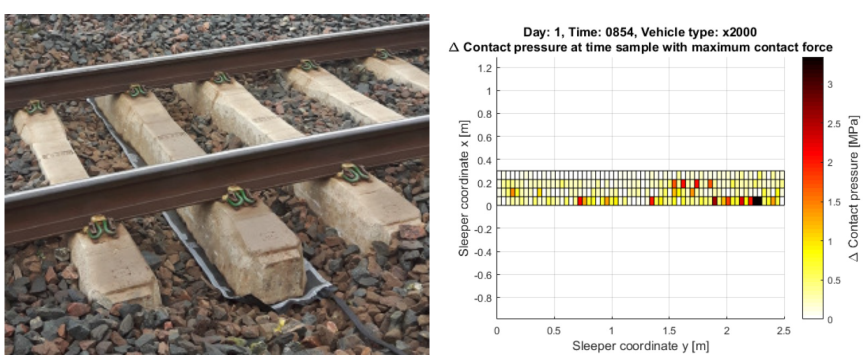

Figure 1 Measurement film installed and example of contact pressure distribution

[1] UIC code 713, Design of monoblock concrete sleepers, November 2004 (1st edition), 25 pp

Appitrack NG: The use of robotics for construction of slab tracks

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Introduction

Alstom is carrying out slab tracks installation through an innovative process with the use of Appitrack NG (New Generation) robots. We combine multiples high-level technologies used in factories and latest scanning technology to maximize the accuracy of track position. For benefits of safety and to be price competitive, our process aims to minimize manual labour needed during the installation process.

Analysis

This innovation started 1995 and makes Alstom a pioneer in the slab tracks construction field. By integrating state-of-art technology that has never been used before to construct slab tracks with Robotic technology and Wireless Laser Trackers. Up to date, our NG (new generation) robots are able to insert baseplates into the fresh concrete slab track using robotic arms with very high precision. Before each insertion, the machine calculates the precise position of each baseplate with help of the on-board guiding system, a tailored algorithm system associated to wireless laser trackers. The robotic arm takes the baseplate and insert in the correct position while vibrating the baseplate. The vibration is important to eliminate air bubbles and ensure the adequate adhesion to the concrete. Once the concrete is hardened, the rail installation is carried out and the track works are finished.

Conclusions

Our experience in using the Appitrack for the previous and ongoing projects have shown that robot technology is here to stay. This technology is price competitive, reliable, safe and accurate. Continuous improvements aim to reach the same speed of construction of slab track to ballasted tracks. So far the use of Appitrack New Generation has been used in the Riyadh Metro where it has shown to be reliable and returned full customer satisfaction.

Figure 1 Appitrack

Efficient upgrading of freight railways

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Introduction

The European objective of a modal shift of freight transports to railways will require extensive upgrading of existing railway lines since very few dedicated freight railways are currently being built and existing lines were built for traffic demands at the time of construction. The transition to increased and enhanced railway freight operations can be costly and complicated. Further, "upgrading" may imply e.g. higher loads, more frequent operations etc. Different forms of upgrading raise different demands on the infrastructure.

Analysis

To minimize negative effects, a guideline for upgrading was developed within the Capacity4Rail project (Paulsson, 2017). This presentation discusses possibilities for upgrading of substructures, bridges, tunnels, and track structure. An overview of challenges and possibilities is presented together with examples of operational upgrading. In particular, the presentation will detail structured approaches to upgrading analyses (see e.g. Fig.1) that may allow for substantial savings in costs, time and resources.

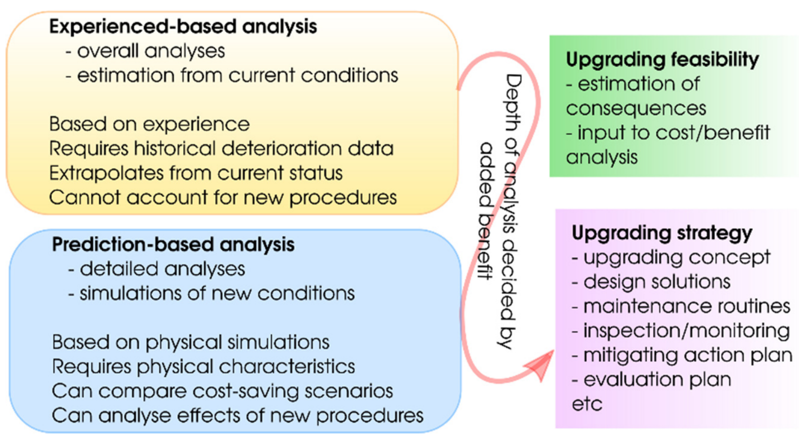

Figure 1 Outline of a two-stage assessment of upgrading consequences on track deterioration

Conclusions

Freight line upgrading using a more streamlined approach as outlined in the (Paulsson, 2017) and summarized in the presentation is a necessity if EU objectives on modal shifts in transportation are to be met. Further, the presentation will show why a political drive is necessary to increase efforts to upgrade freight lines.

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LCC for New Ballastless Track (NBT) vs ballasted track experiences from France

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Introduction

Alstom co-developed NBT for main-line owners seeking a concrete track i.e. a railway track with extensive lifespan and high infrastructure availability, which can be installed faster than traditional slab track, and be operated for mixed traffic. The aim of this study is to compare the LCC between traditional ballast track and NBT solution.

Analysis

NBT has an innovative slab design inspired by concrete pavement experience. The construction process is derived from the service-proven Appitrack technology which allows higher construction rates with 300 m of track laid per day and schedule of track laying reduced by 40%. NBT is designed with a track life of 100 years, regardless of the line's traffic density as opposed to ballasted tracks. This study covers;

- life phases of a line: construction, routine maintenance and intermediate regenerations;
- It takes into account the impacts (of maintenance and renewals) on the capacity of the line and so on commercial incomes;
- It integrates the actualisation and inflation parameters;
- It includes a cost of regeneration of NBT after 100 years

This approach and this tool are adapted to allow comparative studies in the context of a specific project between different constructions solutions, including NBT and other types of tracks.

Conclusions

An estimate performed with the assumptions set out above leads to a reduction in maintenance costs by 22% of the NBT compared to ballasted tracks. The main points of difference concern saving in Tamping and operations on ballast, Straightening of distorted rails. In all the studied configurations, the first renewal phase of ballast track leads to an inversion of cost curves. This inversion occurs after 20 years for ballast under French standards and after 8 years for ballasted track under different standards.
Over a period of 100 years, in all cases, the LCC model of NBT appears quickly (≤ 20 years) much more favourable than that of a ballasted track.

Figure 1 – NBT New Ballastless Track

Wave propagation analysis in railway catenary systems

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Most of the Norwegian railway network has been built when the required speed was much lower compared to the current situation [1]. In the last years, a big effort has been put into interventions with the aim of increasing the maximum speed on the lines, in particular concerning passenger trains. One important aspect to be considered, when it comes to talk about higher speed, is the behaviour of the pantograph and the catenary as a dynamic system that acts as one coupled system [2]. To guarantee a continuous contact between the two is fundamental in order to have a constant provision of current to the engine and to avoid electrical arches. An important limitation to fulfilling continues contact with increasing speed is the waves that propagate along the wires.
These travelling waves are generated by the sliding contact between the pantograph's collectors and the contact wire, which is characterized by a variable stiffness due to its many components and its geometry. The theoretical speed of this propagation is well described in the literature [3], but a more detailed analysis on either field measurements performed on operating railways lines or in laboratory test [4] and numerical model, is useful to have a better understanding of the phenomena applied to catenary systems.
In this work, the focus has been oriented to the laboratory tests and numerical models, starting from the analysis of the contact and the messenger wire separately, in order to start with the simplest situation possible, with the idea of studying then the whole catenary as the next step. The laboratory set up consists of a test rig in which different wires can be tensioned to reproduce operation conditions. The test is performed by initiating an impulse, tapping the cable at one end, similar to the situation where a pantograph crosses a point of high change in stiffness, and to record the accelerations in multiple points along the wire [5]. This enables a comparison with an analysis that considers both the speed and the dispersion of the travelling waves. The analysis performed can successively be compared with numerical models and data coming from real operating conditions on the Norwegian railway network [6].

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How to effectively use lumped-mass on the catenary for better dynamic performance

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There are many types of catenaries in Sweden, which are relatively soft compared with the systems in other countries. Even though the geometry of the catenaries can be built perfectly levelled, the catenaries are not continuously supported, so the vertical stiffness variation, propagating wave and wave reflection can cause high dynamic load between pantograph and catenary, especially at high speeds and in multi-pantograph operation. Structural errors, wire misalignment and environmental perturbations further deteriorate the dynamic performance. Today the pantograph-catenary dynamics has become one of the key factors, which limits the operational speed, restricts the multi-pantograph operation and determines the service life of key components in railways. New-built lines can directly apply the advanced catenary designs, but upgrading the vast existing network is costly and time-consuming. Therefore, it is necessary to find a practical and efficient method to enhance the dynamic performance of the existing catenaries.

From the structural aspect, there are many kinds of lumped-masses on catenaries, e.g. droppers, clamps and other fittings, but traditionally they are supposed to give negative impact and kept as light and small to minimize disturbances. These lumped-masses are impossible to be completely removed, but can easily be adjusted during maintenance. However, in other engineering applications, some artificial mass systems are deliberately introduced into their applications to improve the dynamic behaviour, e.g. stock bridge damper for overhead power line, balancing weight on rotating body, and active and passive tuned-mass system on tall structures. These additional mass systems neither reduce the overall capacity nor introduce much dynamic disturbance, but can effectively improve the dynamic behaviour.

In order to use the “unfavourable” lumped-masses on the catenaries and to improve the dynamic performance, we investigate the influence of the additional mass on its resultant dynamic behaviour with a 3D pantograph-catenary numerical model. With help of these investigations, we find that the lumped-masses on the catenaries do not always give negative impact and can improve the dynamic performance, if the mass can be placed at some favourable locations. Tuning the attaching stiffness between the mass and catenaries can provide further improvement and more flexibility. The influence only takes place within a small range and becomes stronger in multi-pantograph operation. The hard-point effect caused by the lumped-mass can be reduced by implementing the mass on the messenger wire by dropper slackening when the pantograph is passing. Therefore, the dynamic behaviour of any location on the catenaries can be adjusted according to the needs to overcome technical difficulties, e.g. for speed increase, in special sections and in multi-pantograph operation. Today for structure supporting or electricity circuiting, there are already many kinds of lumped-masses on the catenaries, e.g. clamps in different shapes and at different weights. In the future, why can’t we implement some artificial masses or tuned-mass systems on the existing catenaries for dynamic reasons?

Are we ready for high-speed catenaries?

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The train speed is increasing in all Scandinavian countries. Norway is building lines for a maximum speed of 250 km/h using their catenary System 25, Sweden is developing a new system, SYT 21/27 for 320 km/h, and Denmark is planning to finish their first 250 km/h line in 2018 using the Siemens Sicat SX catenary system. The experience with these catenary systems will be limited for the particular country for a long time. The behaviour of these systems under train loading will be different to previous systems meant for different speeds and thus loading. A different behaviour will lead to changes in the type and amount of wear. It is therefore very important to have control on these systems from the beginning of their operation. This by doing sufficient tests with monitoring trains at running speed with high enough sampling to identify new as well as old phenomena. In addition, continuous monitoring of the catenary in itself give valuable knowledge about its behaviour, as in Nåvik, Rønnquist and Stichel (2016).

According to EN50317 (2012), the contact force should be calculated using both measurements from force and acceleration sensors below the collector strips. It also states that the sample rate should be greater than 200 Hz or smaller than every 0.40 m, and that they should be low-pass filtered at 20 Hz. This is not good enough for high-speed railways because it is too seldom for finding the correct extreme values, Nåvik, Rønnquist and Stichel (2017). In addition to obtaining the required values in the standard, contact forces can be used to identify changes from time to time instead of waiting until values are outside the limit, Rønnquist and Nåvik (2018). Maintenance can then be much better planned and feedback can be given to codes to include improvements for later designs.

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Optimisation of transition zones between different railway track forms using a genetic algorithm

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Railway lines often contain various types of transition zones between different track forms (Sañudo et al., 2016). At such transitions, there is a structural discontinuity leading to an abrupt variation in track stiffness and as a consequence increased dynamic loads. In this study, the vertical dynamic interaction between a vehicle and a railway track is simulated in the time domain using an extended state-space vector approach. For the linear, time-invariant track model, consisting of a transition zone from slab track to ballasted track, a complex-valued modal superposition technique is applied. Originally, this model was developed by Nielsen and Igeland (1995) for a ballasted track, and it was recently extended to the slab track context (Aggestam et al., 2018).

By considering a multi-objective optimisation problem and applying the stiffness of the rail pads and the sleeper spacings as design variables, the dynamic loads on the track are minimised using a genetic algorithm. The considered dynamic loads consist of the maximum wheel–rail contact force and the maximum load between sleeper/panel and foundation. From the solution of the optimisation problem, a Pareto front is obtained, see Figure 1, which illustrates a significant reduction of the dynamic loads (compared to a nominal track) when the design variables are optimised.

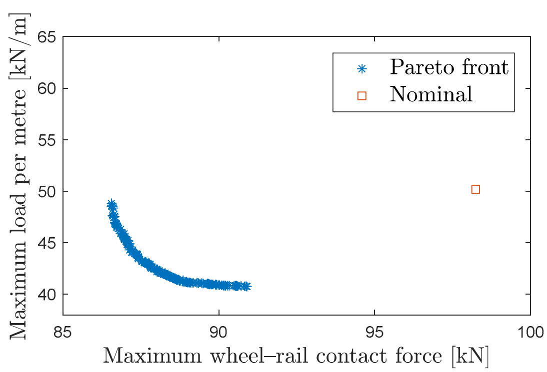

Figure 1 Pareto front of the final iteration of the genetic algorithm.

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FE-simulation of track stiffness along transition zones for high-speed slab track

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Abstract

Track stiffness, $\boldsymbol{k_{track}}$, defined as the ratio between wheel force and rail displacement, is an incorporated parameter of all track components and affects both the dynamic performance of track and the running behavior of vehicle. This presentation concerns finite element (FE) simulation of vertical track stiffness along transition zones for a slab track designed for high-speed lines of 320 km/h. Our objective is to assess track stiffness according to FprEN 16342-2:2017 and in particular we pay special attention to track stiffness variations along transition zones between bridge and plain track as well as due to a very soft area in subsoil.

Figure 1 illustrates the used simulation model, in which the subsoil layer has been divided into subareas A/B, C and D, representing different material properties. Accordingly, three transition zones can be considered. Modelling and solution procedures are based on the Matlab-version of DIFF originally developed at Chalmers for ballasted track and further development has been made by simulating the slab and all other substructure components as a linear elastic continuum and using two-dimensional 4-nodes bilinear isoparametric elements for the discretization.

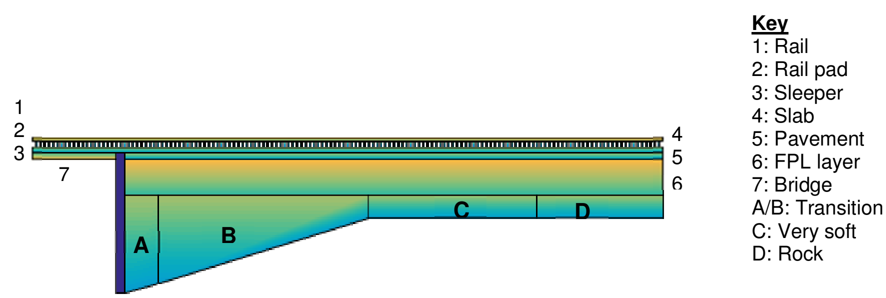

Figure 1 The simulation model includes rail, rail pads, sleeper (block), slab, pavement, frost protection layer (FPL) and subsoil.

Numerous simulations and parameter studies have been carried out. The obtained results have been used for Trafikverket to develop the technical system standard for high-speed lines, TSS version 4.0, in which the requirements for track stiffness and its variations are specified. In particular, by denoting $\boldsymbol{k_{rigid}}$ as the reference track stiffness of a special case which assumes the slab layer and all substructure components are rigid, we propose the following target values for track stiffness $\boldsymbol{k_{track}}$:

$$\boldsymbol{k_{rigid} - 8 \leq k_{track} \leq k_{rigid} + 2} \text{ [KN/mm]}$$

Train-track-bridge interaction for non-ballasted railway bridges on high-speed lines

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Introduction

In the design of railway bridges for high-speed trains, a set of dynamic design criteria are stated in EN 1990/A2. Limits for the vertical bridge deck acceleration and displacement are often of main interest. The limit for vertical deck acceleration origins from bridges with ballasted tracks to avoid the risk of ballast instability, track misalignment and potentially derailment. For bridges with non-ballasted tracks the limit is set to 5 m/s^2, simply obtained as the gravity divided by a safety factor 2, under the assumption that loss of wheel-rail contact will occur at 1g. The vertical deck displacement is related to the level of riding comfort and is based on a limited set of simulations carried out by ORE D160 in the 1980ies and later by ERRI D190/RP5 in the 1990ies.
In the present study, the correlation between the vertical deck acceleration and the risk of derailment as well as the correlation between the vertical deck displacement and the car body acceleration is investigated. This is accomplished by a large parametric study based on a 2D train-track-bridge interaction (TTBI) model for non-ballasted bridges, illustrated in Figure 1.

Conclusions

Based on the parametric study, it is concluded that the current limit for vertical deck acceleration of non-ballasted railway bridges is very conservative. The risk of derailment measured as a wheel-unloading factor or duration of contact loss does not pose any safety risk until the vertical deck acceleration exceeds 30 m/s^2, compared to the present limit of 5 m/s^2. The vertical deck displacement and the resulting car body acceleration seems to be in line with the current regulations in EN 1990/A2. However, both the wheel-rail contact forces and car body acceleration are highly influenced by the rail irregularities.

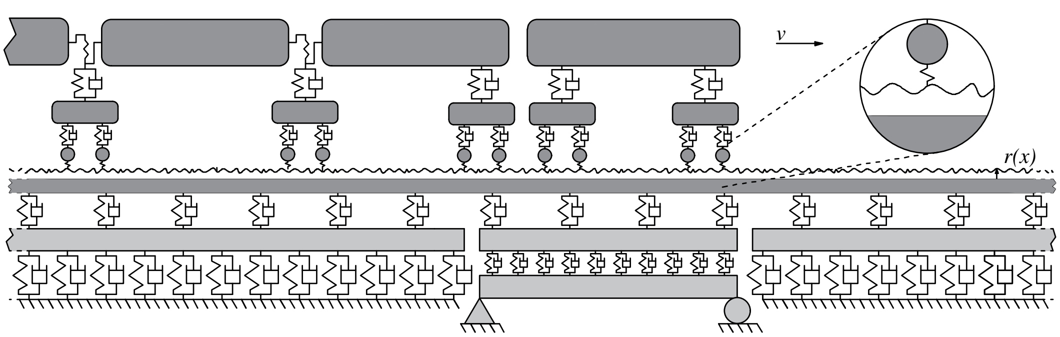

Figure 1 2D Train-Track-Bridge Interaction model.

Extending maintenance intervals with confidence – How digitalization and innovation in bearing technology supports sustainable railway industry growth

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Introduction

For Railway Industry to sustain and grow in the competition towards other modes of transport, a 30% reduction in cost of operation and maintenance with identical traffic, and a doubling of the traffic capacity on existing network at the same operating cost is needed. This challenge calls for innovations reducing life cycle cost without compromising reliability. By prolonging bogie maintenance intervals from 4 to 5 years, savings of 2 000 EUR per bogie per year can be gained. Wheel bearings are safety critical components and often the "bottleneck" dictating bogie maintenance intervals.

Analysis

Today's time based maintenance schedule implies underutilization of bearing potential. To move to a condition based set up, with confidence, requires monitoring systems able to identify potential damages well before they lead to failures. Digitalization has helped this development significantly and sensors (collecting vibration, temperature, etc signals) can now directly communicate to a dedicated cloud based analysis service over the cellular network and automatically be turned into actionable information for Railway operators. While a condition monitoring system enables better utilization of bearings it does not affect the bearing performance as such. Hence, to be able to reduce life cycle costs even more there is a need to work also on the bearing performance side.

Theoretical analysis and practical experiences show that grease life is one of the most limiting factors for maintenance intervals. Investigation of failure modes of wheel bearings shows that in the vast majority of cases, failures are generated on the raceways (so called surface or wear initiated failures). If the grease does not work properly, it leads to raceway surface damages. Besides the amount of grease in a bearing, the most powerful influence on grease life is temperature – a 15°C reduction in operating temperature can double grease life.

Conclusions

User friendly and cost effective condition monitoring solutions are now reality and will support the shift from time based to condition based maintenance regimes. To increase bearing life, the performance of the grease has to be maximized and operating temperature must be reduced.

Rolling contact fatigue on heavy haul locomotive wheels. A case study on LKAB IORE locomotives at Malmbanan

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The mining company LKAB uses IORE electrical locomotives to haul their iron ore trains. During 2001 – 2005 the technical wheel life length was found to be 930,000 km. From around 2006, the wheel life started to decrease because of increased rolling contact fatigue (RCF), dropping to around 300,000 km. A serious of actions was undertaken to restore the wheel life up to present date. These actions includes field tests with revised wheel profile, a new better wheel steel grade and a combination of new steel grade and revised profile, limitation of electro dynamic breaking, lower axle load and use of top of wheel lubrication. This case study will present and analyze the results from the different actions tested in the field on the Iron Ore Line Malmbanan.

Figure 1 IORE locomotive no.128

Wear of tread braked wheels and brake blocks

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Tread brakes are a commonly used braking system in trains, used either as the single system or as part of a blended system where several braking systems are utilised in combination. Considering block materials used for tread braking, the reduction of railway rolling noise has propelled a shift from cast iron brake blocks to organic composites and sinter brake blocks. However, inside these families of friction materials the friction and wear properties vary substantially. Moreover, some brake block materials might cause uneven wear of the wheel tread which may lead to unstable running of the train. This may lead to an increased need for maintenance of the wheelsets, which is a main part of the total life cycle cost.

In the current study, the Archard model (1953) is applied for the calculation of accumulated wear with temperature-dependent wear coefficient, see Vernersson and Lundén (2014). Wear of the wheel tread and brake blocks is calculated using fully coupled simulations for repeated stop braking. The finite element model used in simulations is shown in figure 1. Results for accumulated tread and block wear will be presented.

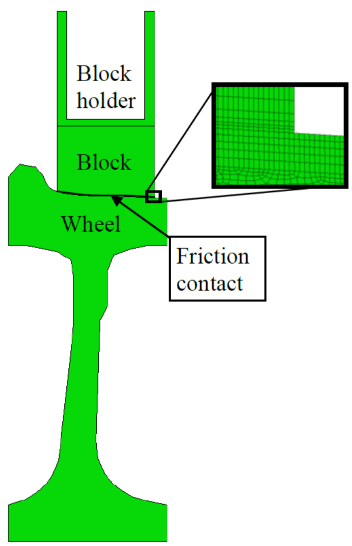

Figure 1 Finite element model of tread brake with meshes close to contact.

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Implementation of traction batteries into mainline railway vehicles for emission-free rail travel

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Introduction

Given the customer needs and the development of high-power and high-energy battery cells during the past decade, traction batteries are becoming a viable alternative to fossil fuels in the mainline railway sector. Given the fact that regional railway lines in Europe are often not longer than 50 km and therefore in the range of a Battery Train, Bombardier Transportation decided to develop a Battery-Electrical Multiple Unit.

Analysis

So-called "Accumulator Trains" with lead-acid were common in Germany from 1907 until 1996, Troche (1997). Due to their low weight and large amount of batteries installed, these trains could cover distances of up to 400 km with battery power. In the 1970s over 200 Battery trains circulated in Germany. Due to low Diesel prices and higher performance requirements the Accumulator trains died out. In 2016 Bombardier Transportation started a Government-funded R&D project whose purpose is to adapt the existing lithium-ion battery for mainline applications and homologate one of the very first modern Battery trains for zero-emission regional transport in Germany. The development includes the adaptation of the battery system and its' mechanical, electrical, functional and operation integration into the vehicle as shown in Figure 1.

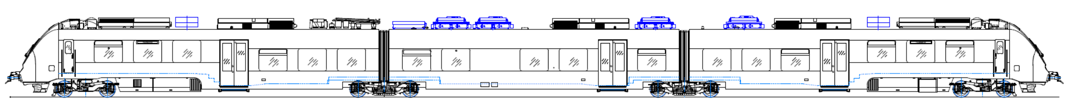

Figure 1: Layout of the TALENT 3 Battery Train with roof-mounted Traction batteries marked in blue

Conclusions

The feasibility of battery-propulsion on railway vehicles is being demonstrated with the R&D train which currently being tested and homologated for passenger operation. However, it is yet to be shown how the new traction system can be implemented into the existing railway landscape in terms of re-charging times, performance, battery life-time, range and operability. The correlation between energy consumption, installed battery capacity and cost is crucial. With Battery traction the overall energy efficiency of the train and correlated "supersystem" gets an even more important role. However, it can also be shown that with a Total Cost of Ownership calculation over 30 years, a fully electric Battery Train will be more cost- and energy-efficient than comparable Diesel trains.

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Reduced energy usage at train operation (Shift2Rail)

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Abstract

The ongoing Shift2Rail research programme is to monitor the impact of its research and demonstration activities, in particular by means of three high-level Key Performance Indicators: Capacity, Life Cycle Cost and Reliability. One indicator at a lower level, but still important, is the energy usage at train operation. To coordinate the energy efforts a so-called Cross Cutting Activity is launched through the project FINE-1 (Future Improvement on Noise and Energy 1), also including noise from trains. Trafikverket is one of the partners in this project and has engaged KTH in the project.

A first step in the project is to define an energy baseline for the four main service categories of Shift2Rail: High-speed, regional and urban passenger trains as well as freight trains. State-of-the-art technology with respect to energy performance is surveyed and representative train configurations and operational conditions are defined (Figure 1). A software for train energy simulation is being developed through the Shift2Rail open-call project OPEUS. The improvements in energy performance in Shift2Rail are to be evaluated with this software. Reductions in energy usage at train operation are foreseen by improved traction and braking technologies, reduced running resistance, eco-driving, more efficient energy supply etc.

An important aspect is also energy labelling, that is how train energy performance can be quantified in a simple way so that different trains can be compared with each other and also how trains can be compared with other modes of transport from an energy perspective. In the European Union there are many products that have standardized ways of labelling their energy performance. So far the labelling mainly applies to household products, see the example of a washing machine in Figure 2, but efforts are now ongoing to also include other sectors like transport. For transport the units might be kWh per person-km or net-tonne-km.

Main Service Category	**Sub Service Category**	**Max. Speed** [km/h]	**Average Station Distance** [km]	**Traction system**
High-speed	High Speed 300	300	100-150	electrical
Regional	Regional 160	160	10-25	electrical
Urban	Metro	80	1.5-2.5	electrical
	Tram	70	0.3-0.8	electrical
Freight	Freight Mainline	120		electrical

Figure 1. Operational conditions for trains

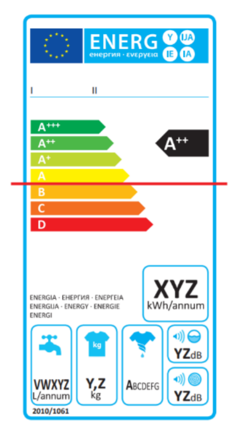

Figure 2. EU energy labelling for washing machines

Single-lead junctions for merging from rail yards onto double tracks – a capacity analysis

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Introduction

In the years to come, the railway network in the eastern part of Norway will go through great developments as part of the InterCity-project to handle the expected population growth. With the entire InterCity-project completed, the number of travellers per year is expected to increase from todays 8.8 million to 17.8 million (Samferdselsdepartementet, 2016-2017). The quantity of rolling stocks will need to increase significantly to cover the increased demand. Hence, the demand for train stabling will also increase, and new rail yards will be needed. Some of these rail yards are considered to be built along the double tracks of InterCity, which are designed for speeds of 250 km/h.

Analysis

Single-lead junctions with waiting tracks for the merging from rail yards onto double tracks is one of the options being considered along the InterCity tracks. The aim of this study is to address the effects of these single-lead junctions with waiting tracks on the traffic volumes and line speed, and the resulting traffic delays. The capacity analysis tool LUKS is used to analyse the different situations. The analysis is based on timetables with varying combinations of train volumes, train speeds and frequencies. Both predefined analysis scenarios and a case study of an existing Norwegian railway line is modelled and analysed in LUKS.

Conclusions

The study should conclude with recommendations for situations where single-lead junctions are suited. In situations where single-lead junctions with waiting tracks results in unacceptable delays, grade-separated junctions will be considered. The most important factors leading to waiting during the merging process will be identified. Based on the results from the capacity analysis, and based on economic considerations, the optimal solution for the placement of the rail yards and junction design can be found.

Figure 1: A sketch of the infrastructure model from LUKS.

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WRIST – Innovative welding processes for new rail infrastructure

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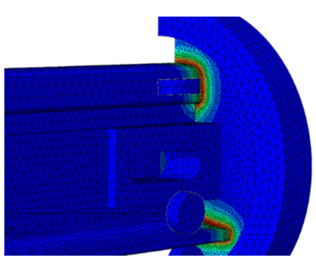
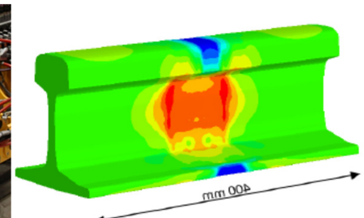
WRIST is a Horizon 2020 project funded under the Mobility for Growth 2014-2015 work program. The objective of WRIST is to develop and demonstrate flexible and cost-effective joining processes for rail products. Two innovative methods for joining rails; automatic forged aluminothermic welding (ATW) and orbital friction welding (OFW) are developed with the aim to both reduce the width of the (HAZ) and minimise the loss of mechanical properties in the weld zone. Lower life cycle costs for track maintenance and renewal will be achieved by eliminating the source of higher dynamic forces at "cupped" or irregular geometry welds.

The present paper describes the numerical modelling of the two methods. The orbital friction welding method uses an eccentrically rotating intermediate disc between two rails together with compressive forces to create friction heat. A heat generation model has been developed and validated in a separate experiment with friction welding of thin walled pipes. Process parameters can then be chosen for the OFW method to obtain the desired micro structure and weld quality. In the second method an alumino-thermite welding process has been complemented with a forging phase shortly after pouring of molten material, which will reduce the width of the heat affected zone and reduce thermal and casting defects. The left Figure shows calculated temperatures in the rail and disc in the early stage of the OFW process, the middle Figure shows the ATW equipment and the right figure shows residual longitudinal stress after the ATW method (tensile streses are red, compressive blue).





Thermo-mechanical analyses of discrete defect repair process for rails

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Discrete defects in a rail head may form due to aggressive wheel–rail contact in terms of thermal and/or mechanical loads, or due to indentations from foreign objects trapped in the contact. If large, such defects need to be repaired or the rail section removed. These are costly operations that cause operational disturbances. Discrete defect repair (DDR) procedures that include repair welding provide a cost-efficient alternative to rail replacements. Investigations of such repair methods have been conducted in the frame of the European project In2Rail and reported in Deliverable report D3.1, see Kallander (2017). The present work has been focused on investigating a novel DDR procedure through numerical simulations. The new technique employs significantly lower preheat temperature (80 °C in contrast to widely used 350 °C) and equipment that can be carried to the working place. However, the low preheating temperature introduces high temperature differences between the molten filler material and the surrounding rail steel. This may lead to the formation of defects and has to be assessed.

The quality of the weld is highly influenced by the thermal field induced by the repair welding process. This topic was investigated in detail by thermal analyses in Maglio (2017). The study showed the possibility of numerical simulations and investigated in detail requirements and sensitivities of numerical models. In particular, it quantified the sensitivity related to both simulation parameters and to experimental measurements. The thermal analysis has been extended to a thermomechanical analysis that is able to investigate the residual state of stress after repair welding. Such analyses can be used to compare repair welding methods and also investigate the sensitivity to different operational parameters.

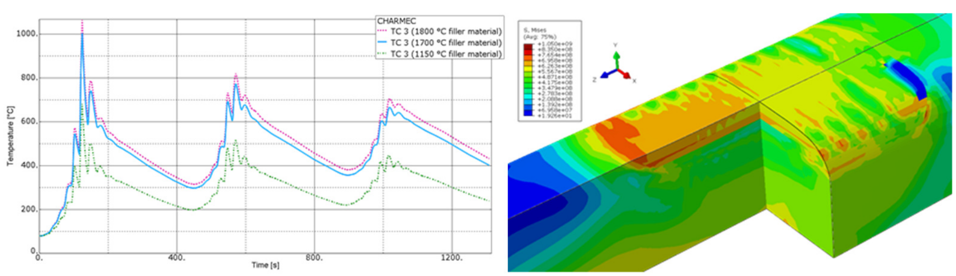

Figure 1 Results from numerical simulations of DDR process in the welded rail: thermal histories for different molten filler material temperatures (left) and von Mises stresses at the end of the cooling stage (right)

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Risk-based maintenance for rail fasteners

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Introduction

Rail fasteners are important for track configuration. Failures can lead to misalignments in the rail with respect to the sleepers and compromises in track resilience. These can in turn lead to undesired consequences such as derailment and aggravated damages to other track components. Unfortunately, the current inspection and maintenance regime for rail fasteners does not adequately address the credible failure modes (Setsobhonkul et al., 2017). It also tends to be reactive with potential for further optimization in terms of resource allocation. In response to these improvement opportunities, a risk-based maintenance philosophy, driven by a risk management framework, had been proposed for rail fasteners. This study focuses on the development of the enabling framework and the subsequent demonstration and analysis of which.

Analysis

The maintenance framework was primarily developed from ISO 31000 with underlying principles inferred from other applicable international standards. Reliability tools were then incorporated, allowing practitioners to arrive at an appropriate combination of reliability tools based on the circumstances under which the assessment is to be conducted. The resultant framework was then applied to the imbedded anchors of rail fasteners to simulate how it works and how it can bridge the gaps identified in the existing inspection and maintenance regime. After which, the framework was analysed by varying the parameters and assumptions used in the case study. This unveils the limitations that the framework may face and, accordingly, identifies the provisions necessary for meaningful risk-based maintenance outcomes. The general findings were then incorporated to finalize the risk management framework. It was highlighted that, before initiating on other failure modes of rail fasteners, the framework should be similarly simulated and analysed for each of them to identify any unique provisions.

Conclusions

It was found through the analysis that the lack of failure data can potentially undermine the accuracy of quantitative risk analysis. In this regard, help can be rendered from international rail networks; failure data can be consolidated and analysed at the industry level to support the implementation of risk-based maintenance at the corporate level. Where lack in failure data is inevitable, the qualitative risk analysis aspect of the framework can be leveraged upon to drive a risk-based maintenance approach. It is envisioned that the proposed risk management framework can serve as an enabler for the inspection and maintenance of rail fasteners to shift towards a more risk-based approach.

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New high speed tracks in Sweden – technical specifications for track construction

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Sweden is currently planning for new high speed lines. Trafikverket as infrastructure manager is charged with building the connections Stockholm-Göteborg and Stockholm-Malmö. The lines will be designed for a top speed of 320 km/h. Maximum permissible speed on existing tracks in Sweden is 200 km/h (with only one exception, Bottniabanan at 250 km/h). Hence, technical requirements for the new tracks will be different and tolerances possibly tighter in order not only to accommodate the planned higher speed but also to sustain a high availability of the system. Therefore, Trafikverket is currently establishing the technical requirements for the track, teknisk systemstandard (TSS).

The TSS will state all requirements, mainly related to the higher speed, that are not covered by existing technical specifications. Some of those requirements will push the boundaries of current knowledge for track construction in Sweden. Even though there are high speed tracks in other countries, technical solutions cannot always be copied but have to be adapted to Swedish conditions or new solutions have to be found. The requirements which are covered by this presentation are on track alignment, maintenance plan, accommodation of different speeds, distance between tracks for broader Swedish train profiles and how to build slab track for Swedish conditions. The presentation will highlight challenges that have to be met in order to accomplish the desired high speed service in Sweden.

Figure 1: High speed slab track under construction in Japan 2014 (courtesy of Elin Söderström).

The economic service life of track

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Analysing life-cycle-cost of track depicts (re-)investment causing more than 50% of total track cost. Thus the identification of the economic service life is of major importance for reducing track costs. This requires calculating the economic service life of track. The Institute of Railway Engineering and Transport Economy developed a methodology called "annuity monitoring". The presentation will focus on three topics, a description of methodology for identifying the economic service life, the prediction of maintenance demand as core element, and the possibility of ranking of projects.

Description of Annuity Monitoring

In principle the economic service life is reached as soon as the increase of maintenance costs for increasing service life overshoots the decrease of the depreciation due to increasing service life. As the decrease of the depreciation can easily be calculated, forecasting the maintenance demand is the main challenge for identifying the economic service life.

Prediction of Track Maintenance Demand

Based on time sequences of track data trends of degradation for the specific track section as well as its single components can be analysed and used for predicting the entire maintenance demand. Furthermore expectable permanent slow orders due to overaged track needs to be predicted as well. Prediction of maintenance for different track components did not need any data to be recorded. However, it was necessary to develop new ways of analysing existing data. Examples of these methods are the fractal analyses, standard deviation of gauge, and change of rail inclination.

Ranking of Projects

As the maintenance demand can be analysed it is possible to calculate total track cost over service life. The increase of the total cost after reaching the economic service life allows ranking of different projects in case of budget restrictions.

As this methodology is already implemented for main projects at Austrian Federal Railways Infrastructure (OeBB) since 2011, the preciseness of the methodology and thus the maintenance predictions is already verified for a prediction period well above the period of six years defined for project decisions at OeBB. This finally allows discussing some typical results.

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3d characterization of RCF crack networks

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Introduction

Rolling contact fatigue (RCF) damage is becoming more frequent with increased traffic, accelerations, and loading conditions in the railway industry. Defects which are characterized by a two-lobe darkened Surface and a V-shaped surface-breaking crack are defined as squats. The origination and propagation of squats in railway rails is the topic of many recent studies; the associated crack networks develop with complicated geometry near the Surface of rails, but can be difficult to detect and distinguish from normally existing head checks in their early stages, using in-field non-destructive detection techniques. After cutting out damaged sections of rail, there are a number of options to characterize the damage. The aim of this study was to evaluate different methods to geometrically describe squat crack networks; through X-ray radiography complemented with geometrical reconstruction, metallography, X-ray tomography, and topography measurements. The experiments were performed on squats from rail sections taken from the field. It was found that observations made using one method can sometimes explain limitations of the other methods. Furthermore, an accurate description of the RCF crack network geometry can be achieved using a combination of the different methods investigated

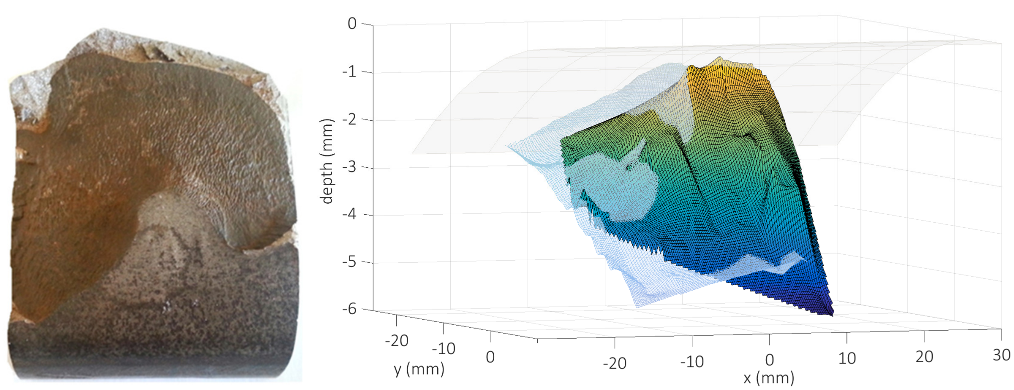

Figure 1 (a) Squat crack taken from the field, and (b) geometrical reconstruction.

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Differential wear modelling - effect of weld-induced imperfections on rail surface quality

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Introduction

Welding process involves high thermal input that results in a so-called heat affected zone (HAZ) on either side of the weld. The metallurgical properties within HAZ vary from the parent rail. This includes a variation in hardness and wear resistance along the surface which causes differential wear and deteriorates the rail surface quality (see Figure 1).

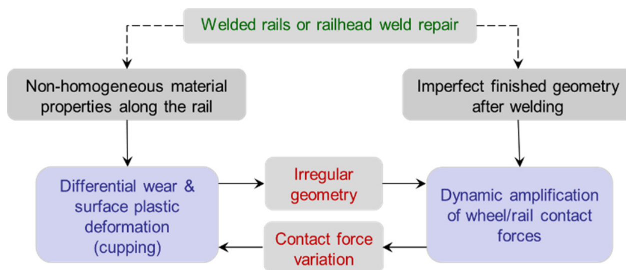

Figure 1 Deterioration loop due to weld-induced imperfections

Analysis

A methodology is introduced to enable prediction of differential wear along the rail. The method incorporates vehicle-track dynamic interaction, wheel-rail contact and wear modelling to predict long-term longitudinal rail profile evolution. The effect of different contact and wear modelling features on the results is investigated. As a case study, the effect of local hardness inhomogeneity along the rail due to aluminothermic welding repair of rails is considered.

Conclusions

Geometrical degradation can be effectively controlled by limiting the length over which the hardness variation occurs, without the need for controlling hardness (see Figure 2).

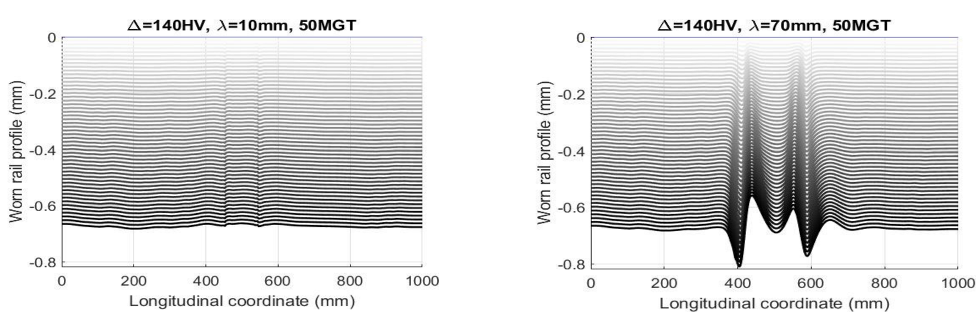

Figure 2 Simulated rail profile evolution for different HAZ lengths

Simulation of plasticity and wear in railway crossings

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In railway industry, high maintenance costs are related to track switches and crossings (S&C), often because of the need to repair or replace rail components. The costs can be reduced by choosing an appropriate material for the components of the S&C and knowing when to perform preventive maintenance. In order to achieve this, it is integral to predict and compare the long-term damage and performance of different steel grades by simulations.

The main damage mechanisms that influence the life of the switch and crossing rails are accumulated plastic deformation, wear and rolling contact fatigue, see Johansson et al. (2011). The objective of the current study is to simulate and compare the former two mechanisms for two materials used in crossings: high strength pearlitic steel R350HT and austenitic manganese steel Mn13.

To compute the plastic deformation for the selected steel grades, a cyclic plasticity material model proposed by Ohno and Wang (1993) is utilised. The Archard model (1953) is applied for the calculation of accumulated wear in the crossing (see preliminary results in Figure 1). Results of simulations of material degradation for given traffic conditions using the two materials will be presented.

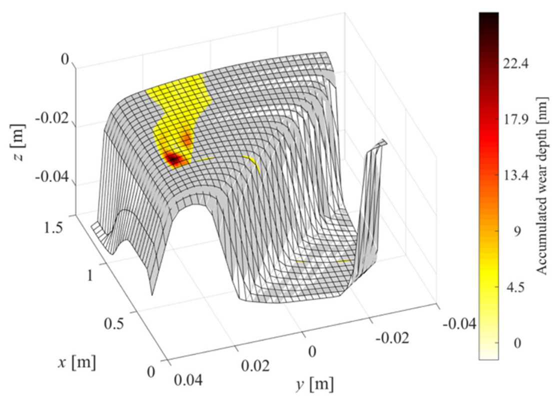

Figure 1 Example of accumulated wear for R350HT.

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Effects of friction management on rail corrugation

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Introduction

To cross the river Verdalselven on the Nordland line, the track makes two narrow curves to enter the bridge on each side. The curve radius is 262 m, respectively 267/256 m in the south and north end of the bridge. Due to corrugations in the curves degradation of ballast and sleepers initiated track renewal summer 2017. The rails were not renewed, but ground, because of little railhead wear. Together with Rolfsen & Juell AS, agent to LB Foster, Bane NOR initiated a trial during which Top of Rail friction modifier KELTRACK was deployed in the critical area to reduce the initiation and development of corrugation.

Technology

The two main mechanisms contributing to the generation of rail head damage in form of rutting corrugation are fixation of the excitation frequency as well as material damage/wear. By applying a friction modifier into the wheel-rail contact on top of rail both of those two factors are being addressed. On one side stick-slip oscillations are being prevented by altering the traction/creepage relationship and on the other side the wear factor is reduced proportionally to the local coefficient of friction. This prevents the reoccurrence of corrugation on a reprofiled rail surface, but also reduces the growth rate effectively.

Test and Analysis

Just before and after the rail grinding process in August 2017 the longitudinal profile and surface roughness of both railheads were measured in the curves entering the Verdal Bridge. At the same time, the friction management equipment was installed beside the track in the southern curve. To compare the tempo of corrugation development in curves with and without friction modifier, the curve in the north end was selected as a reference curve. The environment, the climate, the traffic volume and the rolling stock are exactly the same in the two curves.

To follow the development of corrugations measurement was done in November 2017 and shall be carried out once or twice before summer 2018.

Results

After the test with necessary measurements and analysis the intention is to substantiate the influence friction modifier may have on development of corrugation in narrow curves.

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Operation and maintenance issues of top of rail friction modifier systems at a heavy haul line

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Introduction

This study summarises the operation and maintenance issues from the field study using top of rail friction modifier at the Swedish heavy ore line (Malmbanan), located in Northern Sweden and Norway, during the years 2015-17. The present axle load of the heavy haul trains from LKAB is 30 tonnes and a further increase of 2.5 tonnes per axle is planned. Due to high axle loads, rolling contact fatigue (RCF) is a major issue. Friction management is a technique which claims to reduce RCF, however, equipment for implementation of friction management can have many operation and maintenance issues, especially when there are extreme weather conditions.

Analysis

The present study included two different cases, in the first case a wayside equipment was installed just before a sharp curve of 395 m radius. In the second case, an on-board system was installed on a locomotive of the iron ore train operated by the LKAB mining company. To study the practical issues of the top of rail friction modifier equipment, frequent complete inspections of the equipment were made and root cause analyses were performed. During the tests, the on-board system never breakdown during the operation, however, during winters the nozzle gets blocked due to ice and frozen friction modifier. The wayside equipment breakdown frequently and had an availability of 0.3.

Conclusions

- The main conclusion is that the use of a wayside top of rail friction modifier systems is not feasible at Malmbanan as they attract significant maintenance issues and high operating costs.

- An on-board system could be a solution, however, during winters a winter adapted FM is needed.

Derailment risks in operation of long freight trains

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Introduction

Efficient and safe operation of freight trains require assessment of its running behaviour. As the freight trains get longer the Longitudinal Train Dynamics (LTD) part become more pronounced on its running behaviour, especially if the traditional pneumatic braking system is kept. The LTD for a freight train system is complex and depends on varying parameters related to vehicles, infrastructure and operation. As a part of the Shift2Rail project-DYNAFREIGHT (1), KTH is involved in the proposal of safety precautions in long freight train operations by performing three-dimensional simulations and analyzing the derailment risk.

Analysis

A multibody simulation (MBS) model is constructed using GENSYS and 3D simulations are performed for varying wagon configurations on different curves such as S-curves and horizontal curves of constant radius with significant input taken from the propelling test specifications in the standard, UIC 530-2 (2) (Figure 1). The derailment modes of the critical wagons in each case are studied (Figure 2) and the corresponding static Longitudinal Compressive Force (LCF) limits are tabulated.

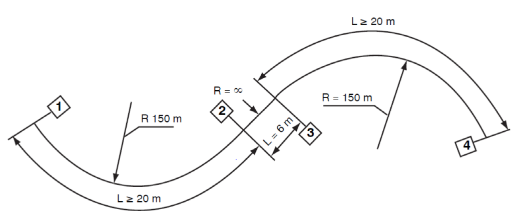

Figure 1: UIC 530-2 curve

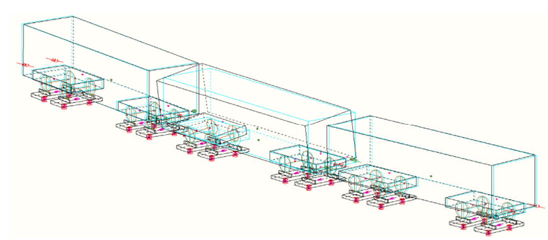

Figure 2: Derailment risk while passing through an S-curve

Conclusions

The LCF limits of the wagons under different operations vary w.r.t the wagon geometries, buffer types, torsional flexibility and adjacent wagon placements. Based on the running conditions, the static LCF limits can be determined using the simulation methodology and compared with the in-train forces for safe operation of long trains.

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Safety critical functions – a generic approach to risk assessment in design of rolling stock

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Introduction

The European Union Agency for Railways, EUAR/ERA, has an ongoing process of developing an approach for being able to make a harmonized and generic approach to risk assessments and safety management of rolling stock. The benefit is to have a uniform method applicable for all variations of rolling stock.

Lloyd's Register has for the last decade developed a generic basis for risk assessment throughout all lifecycles of rolling stock. The method is based on generic safety critical functions, SCF, and includes defining barriers protecting the SCFs verified towards risk acceptation criterions.

Analysis

The SCF is defined as a function necessary to maintain safe operation of the rolling stock. SCF analysis is first introduced in the design process of new rolling stock as a part of the system engineering design reviews. A systematic method is developed to analyse the safety aspects of the system design and to identify and assess design barriers and required maintenance and operational procedures to ensure safe operation. The method is a top down approach to focus on critical failure consequences and eliminate unnecessary analysis work.

Conclusions

The result of the analysis is the best design solutions verified according to risk accept criteria and validated for safe operation and maintenance performance. The implemented design, operation and maintenance measures are defined as barriers.

The generic SCFs and risk assessment method has been successfully conducted to review and validate design in a number of rolling stock development projects as, i.a., Stadler FLIRT for NSB, Siemens MX3000 Metro for Oslo. The presentation will include a practicable example of the analysis of a SCF.

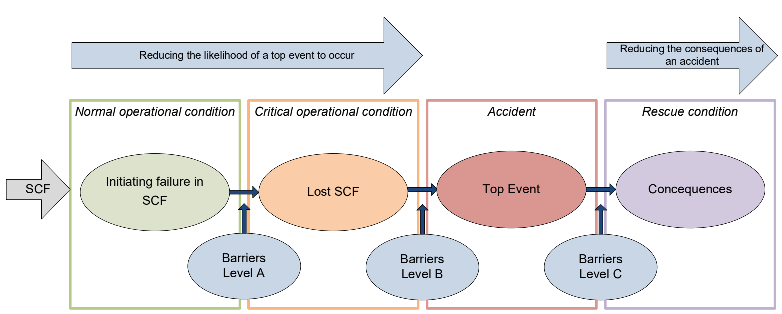

Figure 1 Conceptual illustration of SCF and barriers

The Agile safety case and DevOps for railway signalling systems

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During the last years, there has been an increasing use of agile development methods when developing safety-critical systems, like railway signaling systems.

These methods are introduced to shorten the time to market, to reduce costs and to facilitate updates of the software. Some of the manufacturers of safety-critical systems seems also to be ready for DevOps, Humble et al (2010) and Lwakatare et al (2016). The term DevOps stems from the combination of two processes – development and site operation. New technology has made it much simpler to monitor the operation of the trains and trackside signals continuously.

The Agile Safety Case Approach, Myklebust and Stålhane (2018), could be an enabler for future DevOps processes. This paper discusses such a solution.

It has become important to move towards a process with more frequent updates of the safety software due to:

1. minor differences for e.g. each site specific applications,
2. correction of bugs and errors,
3. reduction of the numbers of SRACs (Safety Related Application Conditions)
4. improved operational feedback
5. improvements due to technology improvements and
6. security issues (IEC FDIS 62443-4-1:2017 and IEC TR 62443-2-3:2015) including safe patching (IEC TR 63069)

The Agile Safety Case forces the applicant to be specific about the quality and safety process together with technical safety aspects, enabling the certification process to be done in parallel with development and enabling the ISA (Independent Safety Assessor) and NoBo (Notified Body) to evaluate the current information at any time in the project.

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Design of blast reduction barrier at railway station platforms

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Introduction

Safety is the first priority in operating transportation and transit systems. The public and customers rely on operators to assure them the reliable and safe day-to-day uses of public transports. However, based on recent factual evidences, extreme physical and cyber threats are no longer uncommon and these unpreventable measures are even more dangerous to the public's daily lives. Such clear examples are the terrorist attacks in Saint Petersburg in 2017, in London in 2017, in Stockholm in 2017, in Brussels in 2016, in Nice in 2016, and so many more. These examples have one thing in common. The transportation and transit systems are the clear target: either on rail, bus, car or truck, etc. (Kaewunruen et al., 2016). This research study further promotes a novel and innovative development and optimization of the platform layout design in improving safety, managing risks, and mitigating uncertainties in a railway platform where perspectives from the humanities and the operations are fully considered.

Analysis

Computational fluid dynamic (CFD) simulations have been used to simulate blast effects from terrorist attacks at a railway platform. Birmingham Grand Central railway station has been modelled by multi-physics finite element method using LS-Dyna. A platform layout design as structural wave barriers has been used to illustrate the hazard risk of train passengers due to explosive air pressures. The reflected air blast from a simulated terrorist bomb has been calculated using LS-Dyna CFD in comparison with the US Army guideline.

Conclusions

This study reveals that the layout of blast barriers does have an impact on the reduction of blast pressure. Increasing the amount of barriers between the explosion and target can increase the chance of survival. The insight from this study can guide a new platform layout design to minimize damage and hazard risks to rail passengers. This research aligns with United Nation's Sustainable Development by creating novel engineering solutions enabling a safer built environment.

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Cybersecurity in railway: Risks and impacts

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Introduction

The convergence of IT/OT and the shift toward using Industry 4.0 in modern railway systems increases the vulnerability of cyber threats, making it hard to predict cybersecurity attacks. It is well known fact that cybercrime rates continue to increase, whether it was WannaCry (Graham, 2017) to disturb information system, hackers (Sternstein, 2012) to affect railway signals or DDoS attack (The Local, 2017) on the website of Sweden's Transport Agency. These occurrences built a solid ground to look seriously into the need to prevent such types of attacks (Active or passive).

Analysis

Railway system has become a potential target for cyber-attacks (Sternstein, 2012; Graham, 2017; The Local, 2017), resulting in adverse impacts on railway facility, services, sensitive information, economy, decision making, productive time, reliability, safety and continuity (Figure 1). Therefore, an attempt has been made to ensure reliability of critical infrastructure system, continuity of business, successful running of government initiatives, data confidentiality, integrity and availability of information.

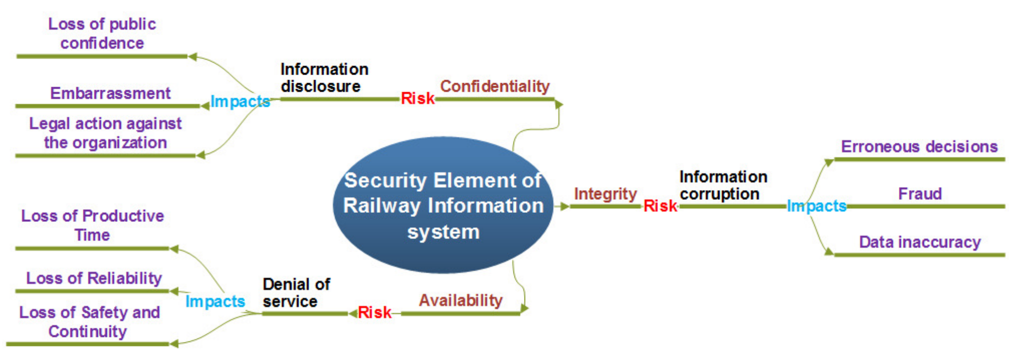

Figure 1 Security elements of Railway Information System along with Risks and Impacts

Conclusions

The paper discusses significance of three security elements (Confidentiality, Integrity and Availability) in the context of railway information system. It further investigates risks corresponding to these three security elements and their impacts on the railway system.

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Aspects regarding track dynamics applying ballast mats on the permanent way on lines for higher speeds in Norway

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In Norway, new lines are constructed and the infrastructure manager (Bane NOR SF) upgrades existing lines for higher speeds.

A simple model for calculating stresses on the superstructure is the well-known Zimmermann's method including DAF (Dynamic Amplification Factor). Experiences have shown that the method is applicable at lower speeds with sufficient accuracy. However, for higher speeds the superstructure acts dynamically different. This is especially true when a third elastic layer being ballast mats, have been installed. The insufficiency of method is that it does not consider aspects in frequency domain.

Installation of ballast mats is an issue to consider on all new lines for higher speeds in Norway due to structure borne noise taking into influencing the external environment.

In order to understand track dynamics with elastic layers installed in the superstructure for higher speeds advanced calculations have to be applied. For this purpose, the presentation will focus on methods, which authors have published.

The presentation will only consider vertical forces due to the assumption of a straight track and tracks with large curve radii. A formula for calculating the dynamic vertical stresses in a complex analysis taking into track irregularities at short wave lengths and irregularities on railhead is:

$$\Delta Q = \frac{\Delta z}{H_r\left(i\Omega\right) + H_W\left(i\Omega\right) + \frac{1}{k_H}} \tag{1}$$

The aspect is to take into account the global track receptance of a track with three elastic layers and the vehicle receptance of a typical Norwegian passenger coach as well as Hertz contact stiffness and carry out the calculation in frequency domain. In the model, the rails are regarded to be continuously supported on elastic layers.

The resonance frequencies of a soft track construction with three elastic layers and other relevant parameters will be looked at.

It is assumed that track deterioration is related to short rail corrugations and short wave lengths of the rails. Short wave lengths will easier occur on track with high elasticity. Attention will therefore be paid to relevant frequencies and how these frequencies will influence maintenance issues.

The presentation will discuss the question whether track receptance and resonance frequencies should be considered as a criterion of appraisement for a track in good working conditions.

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Track stiffness measurements in Finland and utilization of the measurement results

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Abstract

Track stiffness is one of the key properties that determines track performance. In general, poor track stiffness leads to low load-carrying capacity and rapidly developing permanent deformations. Often, the most problematic areas are transition zones where stiffness changes significantly over a very short track section causing high dynamic train loads to the track. Another important point of view is the absolute deflection that can be considered as an indicator of load-carrying capacity of the track. To understand these phenomena, track deflection has to be measured.

A continuous track stiffness measurement device (Stiffmaster) has been developed to conduct measurements. The device measures the vertical geometry of both loaded and unloaded track. Stiffmaster has two separate setups for 140 kN and 225 kN axle loads. Depending on setups, the device consists of three or five lightweight axles that measure the track's vertical geometry first under the axle load exerted by the rolling stock unit and subsequently unloaded. Track deflection is calculated as the difference between the two measured geometries and total track stiffness is then derived from the determined deflection.

The measurement results consists of two different phenomena: absolute stiffness and stiffness variation. The use of variance was considered the best approach for quantifying stiffness variation. It was also noticed that variance varies on different lines. Several lines were categorized according to variance and approximately one thousandth of track meters were considered to require maintenance. This led to a conclusion that every maintenance level needs different limits for stiffness variation. This was reasonable, because speed limit increases while maintenance level improves and higher driving speeds produce higher dynamic loads due to the stiffness variation. It was also noticed that track deflection is simpler quantity to comprehend than total track stiffness.

The absolute deflection over longer distance of track line indicates the properties of subsoil, embankment or superstructure. The load-carrying capacity is the primary interest to solve by means of deflection, but several properties effects simultaneously on that. Measurement results have shown that concrete sleepers produce approximately 0.5 mm less deflection than wooden sleepers do. This leads to different deflection classification between sleeper materials, because larger compression of sleeper does not necessarily decrease load-carrying capacity. Low-volume tracks have also much lower evenness requirements than those of main lines. This was another reason to divide absolute deflection interpretation in three categories.

Comparison of measured track deflection, track inspection history and structural information showed that deterioration of track has often been fast if track deflection is relatively high and structural layers are relatively thin. Very thick structures and embankments decrease deflection and geometry problems. Geometry deterioration may be fast on shallow rock cuttings if the subbase layer is very moist. Latter is one of the typical situations, which track deflection measurements cannot indicate very well.

On the uncertainty of ballast degradation models based on track recording car data in turnouts

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Among different systems of railway infrastructure, turnout systems are playing a central role and in these systems ballast is an important component as it provides support for other components and its failure can be a root cause of excessive failures in other components. A track geometry recording car is typically used to assess the quality of conventional railway tracks but the data has not been widely used for ballast quality evaluation in turnouts. This study represents the application of fractal dimensioning of track longitudinal level (Vidovic et al. 2017) in comparison with other feature extraction methods (Berggren 2010), applicable for root cause analysis of track geometry deterioration, and its usefulness for ballast degradation monitoring in turnouts. An example in Figure 1 shows the effect of a tamping operation in Sep 2016 which is easily observable in the proposed track geometry quality index. Moreover, the gradual deterioration of the track geometry from Nov 2016 to Nov 2017 is traceable from the quality index. The data provided by this index are the basis for developing ballast degradation models in different parts of S&Cs, based on a segmentation scheme.

Adopting a statistical methodology, this study develops and compares ballast degradation models based on regression analysis and stochastic processes (Gamma and Wiener processes). The models are estimated in different parts of S&Cs, in different turnouts, in different geographical locations. The data of more than 80 S&Cs, from 2012 to 2017, in the Danish railway network are analysed.

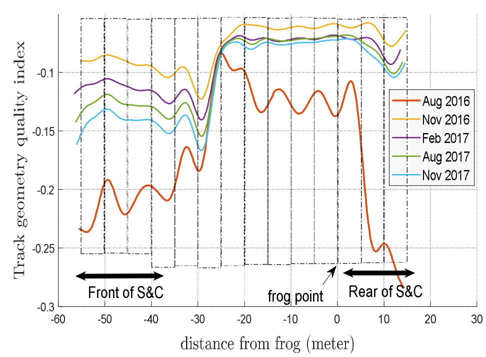

Figure 1: Vertical geometry quality changes in a turnout system

The research gives insight into ballast degradation rate in different parts of S&C including the switching point and the crossing point. The effects on ballast degradation of different contributing factors such as the number of tamping, traffic volume, operating time, and environmental factors are also studied.

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New more elastic turnouts in Finland

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The study concentrates on the basic structure and behavior of four new elastic turnouts, which were installed in Kouvola in autumn 2014 and in Oulu in summer 2016. The main goal of this research work has been to measure the behavior of these new turnouts as comprehensively as possible and compare that to the behavior of the conventional turnout structure in the short but also in long time span.

Study introduces all the new features of these elastic turnouts and explains the purpose of these changes compare to conventional structure, which is still mainly use in Finland. The changes has been made especially on the fastenings, bearers, point machines and locking systems.

Also the monitoring system is introduced, which concentrates mainly on measuring the vertical movements of these test turnouts. In principle, the new elastic components have the largest affect just on the vertical deflection and settlement of track so these things were measured on many single points but also with a continuous method.

The results shows that the elastic turnouts have been working really well during this test period from 2014 to these days. The reversible deflection was measured 4 times in Kouvola and 2 times in Oulu during this period and all off those results were quite smooth and controlled. The Oulu case is still relatively new, so long term behavior is still hard to analyze, but in Kouvola some observations can be made. Few deflection changes were noticed right at the start 2014 in the tip of the turnout V055 and in front of the turnout V059, but the later three measurements revealed that the reversible deflection has not decline, so they are not critical spots at least yet. Still, when the reversible deflection was studied more closely component by component, the behavior of elastic turnouts was remarkably different. The new elastic structure causes significant deflection to happen in the new rail pads between rail and bearers, which means that the deflection between bearers and ballast is much smaller. This can be straight assumed to increase the operating life of ballast and so on the operating time of the complete turnout. The test period was so short that effects of this structural change does not show in the settlement yet. Settlement was about 3-6 mm in the whole test area, which is quite typical value in 2 years time span.

In addition to the vertical measurements, also other things were monitored during these 2 years. One noticeable things was that the temperature inside the new hollow bearers decreased below 0˚C in the cold winter conditions despite the heating elements, which were used inside the bearers. This means that the heating power must be increased in future to ensure that the snow and ice does not accumulate inside the bearer during long winter period.

FFU synthetic sleeper technology – Railway sleeper

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FFU synthetic sleeper

The letters “FFU” stand for “fiber-reinforced foamed urethane”, the material used in Japan to develop a synthetic sleeper. Back in 1978, a company called Sekisui was awarded several prizes in Japan for this technological development.

FFU synthetic sleeper is from a material that has the same material properties as natural timber and can be handled and processed as easily as it can. The synthetic material has virtually the same specific mass as the natural one, yet a very considerably longer service life than the latter, and its weathering proper ties are also superior. In 1980, the Railway Technical Research Institute (RTRI), working in cooperation with the Japanese railways, laid sleepers made of this material on two experimental sections of track in Japan.

In 2011, 30 years after the first field test, RTRI again did laboratory test with sleepers removed from first field test. This 30 years old and under regular train operation used sleepers showed that the technical figures have been decreased a little. The conclusion of this test was that RTRI wrote a letter to JR – Japanese Railway operator - that they can still use these FFU sleepers for the next 20 years

Since 2004, railway sleepers made of FFU have been in use in Europe on railway bridges with open load-bearing structures made of steel as well as under points and crossings as well as slim ties at slab track or with direct fixation systems. In 2018 already in Austria, Switzerland, Germany, Belgium, Netherland, France, Italy, United Kingdom, Norway, Sweden, Hungary.

Final approvals in Europe are given in Germany, Switzerland, Great Britain, Netherland and Austria

Conclusions

In 2008, 2013 and 2015 Munich University of Technology presented the test reports on a research activity into the properties of 160 mm high and only 120 mm high FFU synthetic sleepers positive for 22.5 t axel load and train speed up to 200 km/h.

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Suspension fault detection through condition monitoring

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Introduction

Maintenance of rail vehicle components are usually performed according to time- or distance-based schedules. To make sure that the vehicles are at their maximum availability, maintenance schedules are planned conservatively i.e. most components are replaced before they are fully used. On the other hand, failed components during operation may be left unseen till the next maintenance occasion. Hence, a great number of research works are focused on introducing condition based maintenance where health of different systems are monitored continuously.

Condition monitoring in railway can be categorised into monitoring infrastructure, vehicle and the interaction of the two. Important examples of which are track irregularity, suspension component, and wheel-rail force monitoring respectively. In this paper monitoring of the suspension components is in focus.

Methodology

One suggested method for identifying suspension component failure is looking at the running cross-correlation function between different rigid body modes, Mei et al. (2008). The method is based on the idea that there is a specific relation between different body modes which may change once a component like a damper or spring fails. As an example it can be expected that the relation between carbody yaw and lateral modes changes after a yaw damper has failed. If the change is significant, it can be used as an indicator of a possible component failure. An advantage of the method is simplicity of providing input data by a few sensors. For example carbody modes like bounce, pitch and roll can be extracted using four accelerometers mounted at the four corners of the carbody floor.

This study aims at applying the suggested method to a more realistic vehicle model considering more failure scenarios. Furthermore it would be interesting to find sensitivity of cross-correlation between different body modes to each specific failure.

Conclusions

Preliminary results show good potential in identifying failures through calculation of cross-correlation values. Furthermore a database is provided showing which pairs of body modes can be used to identify a specific component failure. Two major discrepancies from the results by Mei et al. were found. The running cross-correlation values are not being as steady and second being speed dependent. The differences may root in the simplified vehicle model used in the reference study.

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Creating value added for railway track inspection

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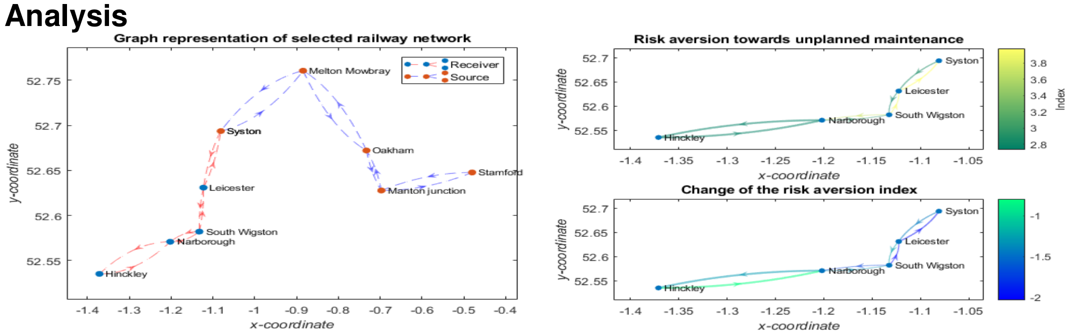
Introduction

Low efficient inspection, i.e., a small deviation between observed values and estimated values of track geometry (and quality) index obtained from a degradation model, negatively affects the overall performance of maintenance (Stenström et al., 2010). A reactive manner to facilitate this shortcoming is to create value added for an inspection. In this study, we propose an innovation in which track inspection data gathered from a set of inspected tracks is processed into uncertainty-related information, and then transferred for the use of tracks waiting, for inspection. The development of the innovation was performed under the five-step value creation framework.

Analysis



(a) (b)

Figure 1 Main elements of the proposed innovation. (a) Identification of source and receiver of information, (b) Comparison of risk aversión index

Figure 1 illustrates the process of value-added creation for track inspection. The information is gathered from inspected tracks (marked in red), and is supplied to the blue-colored track sections in order to update its initial risk aversion index towards unplanned maintenance (refer Figure 1(a)). The difference in the risk index between before and after an integration of the information demonstrates that the proposed innovation adds value to the track inspection, as depicted in Figure 1(b).

Conclusions

Changes in the risk aversion index displayed by railway tracks have not yet received inspection that justifies added value of track inspection to condition-based maintenance. A further discussion on management decision upon this process would be an interesting extension of this research.

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Condition assessment and prediction for asset management of rail tracks

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Introduction

As part of an ongoing strategic innovation program titled *InfraSweden2030*, the Stockholm Regional Public Transport Administration, WSP, Kiwa Inspecta and Luleå University of Technology have undertaken a partnership with the aim to develop a technique for predictive maintenance of railway rails. The technique will be based on condition monitoring by mobile sensors, followed by big data analysis in a predictive model and includes a first field test during spring 2018.

Analysis

The program's aim will be to investigate the most common types of rail damage and the factors that affect the degradation of rails in the Stockholm Metro. Different mobile sensors mounted on a vehicle as illustrated in Figure 1 will be used to capture data to discover existing damage and determine current level of rail degradation. All data captured will be georeferenced by a highly accurate positioning system to facilitate accurate and congruent monitoring of changes and degradation over time.

Figure 1. Vehicle moving at an average speed of 15 km/h with various sensors for rail track condition assessment.

The final predictive model's inputs will then consist of data from three distinct sources, the mobile capture, railway traffic data and other maintenance information, to estimate the degradation and serve as basis for maintenance actions.

Conclusions

LiDAR scanners, industrial high resolution cameras and eddy current sensors have been evaluated and employed to detect damage and provide the inputs to measure the degradation of the rail.

Hell Bridge Test Arena – Steel bridge exploring sensor supported inspections; Challenges and opportunities

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Figure 1. Hell Bridge Test Arena, situated close to Trondheim Norway.

The Norwegian railway network was largely completed by 1962. Most of the original infrastructure have since then been replaced by new components, however this does not apply to the many railway bridges that have persisted and are still in service today. At this time riveted steel bridges was the preferred material and construction type until 1941 when the first reinforced concrete bridges were introduced. There are about 1000 steel bridges in the Norwegian railway network today, most of which were built before 1960. This situation is not unique to Norway, similar characteristics are found in the European and American railway network, e.g. Cremona et al (2013).

The bridge that today is the Hell Bridge Test Arena originates from the five span Stjørdalselva Bridge that was moved to the test site at Hell, see figure 1. This is an open deck steel riveted truss bridge with a span of 35 m. The Hell Bridge Test Arena is a full-scale laboratory serving as a test site for research and development including structural health monitoring (SHM), damage detection, inspection and service life estimation. The main purpose of the test arena is to assess new sensor technology, monitoring algorithms and SHM techniques on a naturally aged structure to establish reliable, cost effective and time efficient inspection methodologies.

Establishing a test arena, such as the one at Hell, is not the first full scale test of an old discarded bridge including several non-destructive tests before final failure. One of the later is reported in Häggström et al (2017). However, the Hell test facility is planed with a long time horizon. With its service life of 114 years, the Hell Bridge Test Arena also has all its, expected and unknown, damage and wear. These faults include both minor and gross errors, where the latter is the primary detection target in the research.

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Monitoring of track and running gear

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Introduction

The presentation focuses on two tasks in the European project Capacity4Rail (http://capacity4rail.eu/): Identification of suitable monitoring targets, and cost–benefit analyses of monitoring. The investigations are reported in (Kabo ed, 2016) and (Kabo ed, 2017). The presentation focuses on monitoring of track and running gear.

Identification of monitoring targets

The investigation identifies parameters that affect operational performance and thereby should be monitored. Challenges in monitoring these parameters, and possibilities of instead employing more easily monitored parameters are discussed. The investigation revealed major heterogeneity in that monitoring purposes vary from essentially pure safety checks (e.g. trespassing) to intricate analyses (e.g. rail degradation). The use of monitoring varies from common and frequent (e.g. track geometry) to essentially non-existing (e.g. sleeper support conditions). Maturity varies from mature solutions (e.g. catenary positions) to solutions in early stages (e.g. image analysis to detect cracks). Challenges vary from easy-to-monitor parameters, to parameters essentially impossible to measure directly (e.g. contact stress distribution in the wheel/rail interface). Monitoring strategies often target indirect measures that are compiled to overview quality indicators.

Cost–benefit analysis

In (Kabo ed, 2017) benefits and costs of different types of monitoring are evaluated. In the evaluation, costs of purchasing, maintenance, potential non-availability, and of potential erroneous measurements are contrasted to benefits related to improved safety, improved maintenance planning, improved operational control, and improved environmental control. The overall assessment is carried out using radar charts (see Figure 1). The report outlines a strategy for successively refined cost–benefit analyses.

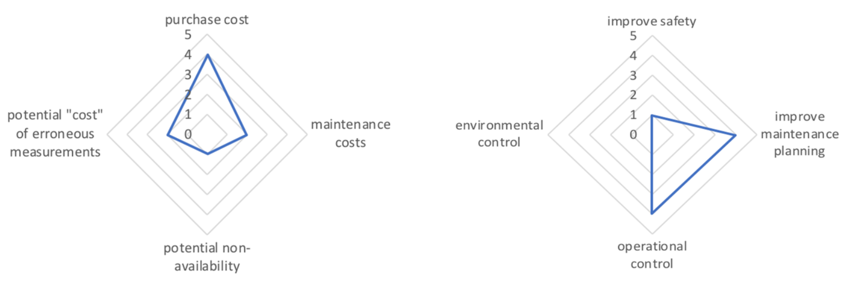

Figure 1 Costs" and benefits of monitoring nominal vertical loads represented in radar charts.

References

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An efficient simulation model for the dynamic behaviour of slab tracks at high frequencies

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The use of slab tracks is attractive especially for high-speed train lines due to their comparatively lower maintenance costs as well as their narrow tolerances for the track, increasing comfort and decreasing wear. From an acoustical point of view, slab tracks are less beneficial. In the literature, ballast-less slabs are said to be about 2 – 5 dB noisier than classical tracks on ballast although rather few studies exist and coherent comparison between different tracks is difficult. Since rolling noise from high-speed trains can lead to costly measures along the tracks, it is important to be able to predict rolling noise with high accuracy already in the planning phase and to identify cost-effective and sustainable measures for its reduction. However, a simulation tool for the accurate prediction of rolling noise from vehicles on slab track in different operation conditions is not yet available. A first step in the development of such a simulation tool is the implementation of a model for the dynamic behaviour of slab tracks in the frequency range of interest, which is for rolling noise approximately from 100 Hz to 5 kHz.

The difficulty when carrying out calculations on such large structures is often the necessary, but computationally expensive use of large numbers of elements. The implemented model overcomes this issue by the use of the waveguide finite element method. It utilizes the fact that both rail and slab geometry have a constant cross-section along the track, functioning as waveguides. This reduces the problem to a two-dimensional geometry while assuming a wave-type solution in the third dimension. Solutions of this type enable both the calculation of the rail response to force input, which is of interest when calculating contact forces, as well as the surface velocities of the structure in the infinite extend of the track, which is crucial when calculating sound radiation.

A slab track geometry based on the Slab Track Austria design by ÖBB-PORR in combination with a standard rail profile 60 E1 has been implemented and evaluated up to 5 kHz. This track setup has also been evaluated in DIFF, a beam theory based approach, by Aggestam and Nielsen. Both models were compared and a good agreement was found in the frequency range up to 1.5 kHz.

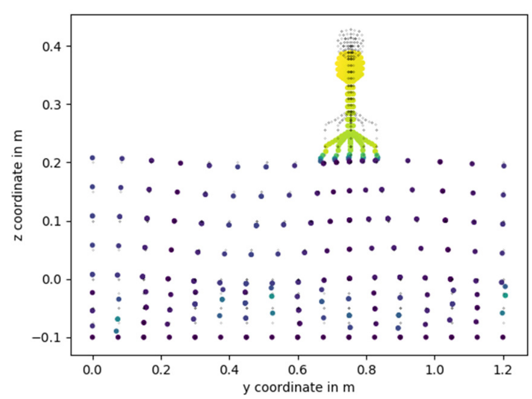

Figure 1: Displaced mesh of the cross section at 1500 Hz. Nodes with negative z-coordinate correspond to a foundation. The slab is placed between 0 m and 0.2 m in height.

Impact noise generated at railway crossings

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Wheel–rail contact positions when a wheel is passing through a fixed crossing are illustrated in Figure 1. In the facing move (from the switch panel towards the crossing panel), the downward motion of the wheel as it travels on the deviating wing rail is reversed when the wheel makes the transition to the crossing nose. Simultaneously, an impact load with a broad-band frequency content is induced. Apart from generating severe rail degradation, this load has another critical consequence in the form of noise.

Impact noise generated on the Rotterdam - Genoa freight corridor has been investigated by numerical simulations and field measurements in a collaboration between Chalmers University of Technology, Deutsche Bahn, Institute of Sound and Vibration Research (ISVR) at the University of Southampton and Vossloh Cogifer. Modelling capabilities of the partners involved have been combined to develop an innovative tool for the prediction of noise levels radiated at railway crossings [Torstensson et. al (2018)]. An extensive field measurement campaign has been launched close to the village Loreley, Germany, located in the middle Rhine valley. Examples of quantities that have been considered are the influence of crossing panel contact geometry on noise and vibration levels. The current work has been reported in IN2RAIL Deliverable 3.2. This presentation gives an overview of this report.

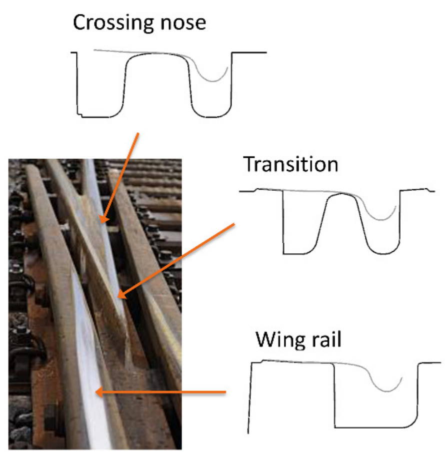

Figure 1. Passage through a crossing (from wing rail to crossing nose) illustrated at three instances when the wheel is in; (1) contact with the wing rail, (2) simultaneous contact with the wing rail and crossing nose and (3) contact with the crossing nose alone.

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A comprehensive survey on the frequency content of curve squeal noise from trams in Gothenburg

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Introduction

Curving noise from trams is a well-known phenomenon to Gothenburg citizens but there has until now been a lack of a systematic and comprehensive compilation of the appearance and detailed character of the problem.

The present study makes use of a large number of recordings from different locations and on different vehicles. The purpose has been to analyse the spectral content of the squealing sound and, based on the large statistical set of data, get a complete picture of trends and spread for vehicle models, wheel maintenance status and curve parameters.

The analysis of sound recordings has been complemented by measurements with acoustic camera and experimental modal analysis of tram wheels to check how the squeal frequencies are related to wheel eigenmodes. Further instrumented curving noise tests are planned during the spring with the aim to correlate measured and simulated curving behaviour (wheel/rail lateral contact position, angle of attack, etc) with squeal occurrence and frequency content for each individual wheel.

The findings of the investigation have been used as input to setting trigger criteria for the on-board system of top-of-rail conditioning/lubrication that is currently being implemented on part of the Gothenburg tram fleet.

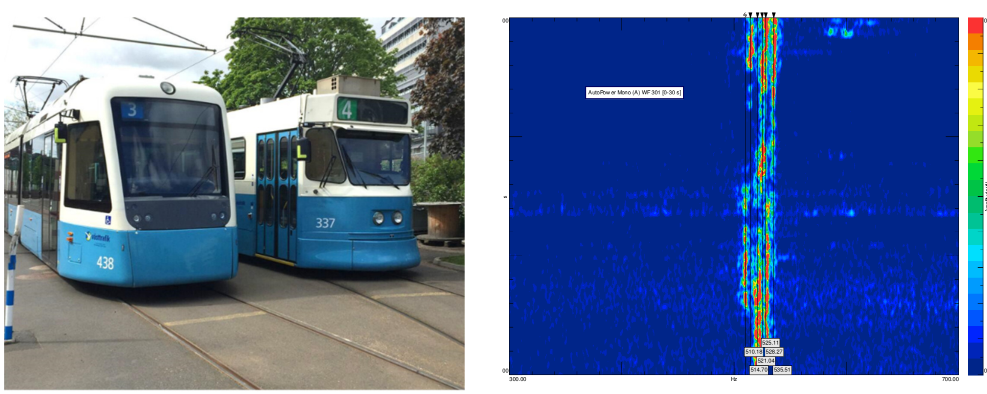

Figure 1. Tram models M32 (left) and M31(right). Spectrogram (300-700 Hz) of tram in curve with audible squeal noise. Intermittent occurrence of several pure tone frequencies around 520 Hz are visible.

Noise reduction on tram network with vehicle mounted top of rail system

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Introduction

To accommodate passenger accessibility low floor tram vehicles have been introduced by manufacturers in recent decades. This can however harm vehicles dynamics as available movement of the bogie is limited, which may lead to higher wheel wear and squeal noise in the wheel-rail contact. To reduce squeal noise, Göteborgs Spårvägar have installed a vehicle mounted friction modifier system, Top of Rail (ToR). Main purpose to use a friction modifier in the wheel rail contact is to sustain a nominal friction level in the contact, about 0.3μ, thereby avoiding build-up of large friction coefficients on the rail head which is one cause for generation of squeal noise.

Analysis

The ToR system was mounted on the first bogie on 23 vehicles, approximate 8% of the total fleet. Number of systems was chosen after initial trials with application of the friction modifier by hand, it was estimated that in revenue service one equipped ToR vehicle would need to pass each part of the track one time every 3-hour period, to sustain a noise reduction effect. A mems gyro sense when the vehicle is entering a turn and applies a spray droplet on the wheel. In addition, GPS is used to geofence and exclude specific parts of the network, for example steep gradients, as an additional safety measure. However, traction and braking tests showed that the breaking distance is not significantly affected by the used of the friction modifier.

Remote monitoring has been used of each system, enabling precise GPS location mapping of when and where friction modifier has been applied on the track system. In addition, a vehicle mounted noise measuring system was developed and mounted on the bogie to accurately measure noise levels. Combining microphones and accelerometers enabled recording of actual noise coming from the specific bogie, filtering out influence of other external sounds.

Conclusions

Reduction of squeel noise in the noise spectra of 450hz to 5khz was attained after introduction of the new system. However, the system likewise flange lubrication systems, needs a large maintaince to keep operational. Vehicle based noise monitoring is belived as a potenital method to measure the status of the whole network.

FricWear 2017 railway tribometer

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Introduction

The FricWear 2017 Tribometer is designed for measuring friction coefficients and wear constants both in the real field and in the laboratory. It is specially designed for measuring friction coefficients and wear properties in railway applications but can also by advantage be used also for many other applications on wear and friction. By measuring in the real field, the important influence of the real third body on the rail (moisture, dirt, water, snow, lubricant deposits, brake pad deposits, cargo deposits, and pollutions), etc., will be considered. For laboratory use it is also suitable for basic education and research regarding friction and wear.

Technical description

A photo of the tribometer is presented in Figure 1

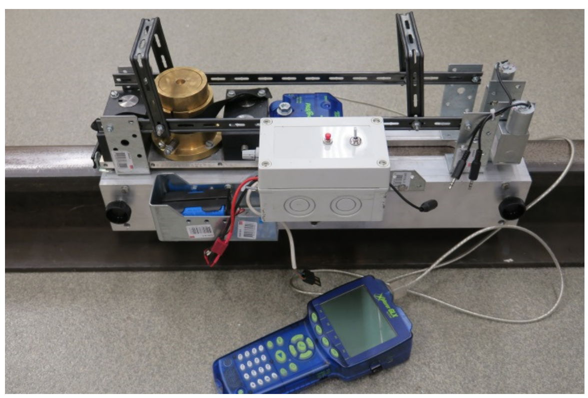

Figure 1 FricWear 2017 Tribometer

Conclusions

Advantages:

- Consider the third body and variable contact pressure and shear speed
- Portable in the field and can deliver appropriate inputs for simulation tools
- Measure both friction coefficient and wear constants for many possible material combinations. Also easy to understand from pedagogical point of view

Disadvantages:

- Only suitable for measurements at short distances on the rail
- Refurbishments of the wear pistons has to be performed before each wear measurement occasions
- Scaling effects are only considered by the contact pressure and speed
- Optical microscope is needed for the wear constant measurements

Improved tribology measurements for wheel–rail interface

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Introduction

Friction between the wheel-rail interface plays an important role as it can affect various surface damages such as wear, RCF, corrugation, and noise. In railway related research, friction is mainly measured in laboratories using a pin on disc or twin disc (disc-disc) equipment. Such laboratory tests lack realistic third body and in many cases also lack realistic surface roughness. Besides, variation in track condition due to weather, ground condition and aging is also neglected. However, performing measurements in the real field, the important influence of the third body (moisture, dirt, water, snow, lubricant deposits, brake pad deposits, cargo deposits, and pollutions), etc., can be considered. Therefore, to have realistic results from the fields, a handheld tribometer is developed at the Lulea University of Technology, Sweden, which can be easily carried in the field to measure friction coefficient and wear.

Analysis

The table below shows the average wear constant and the friction coefficient results, when performed in laboratory and field. In the case of dry surface, the FricWear-2017 tests results lie in the wear range measured for the top of the rail using pin on disc laboratory tests by Jendel (2002) and Zhu et. al (2013).

		Dry (No FM)	FM
Lab test	Friction coefficient	0.28	0.12
	Wear constant	0.9×10^{-4}	6.7×10^{-5}
Field test	Friction coefficient	0.57	0.31
	Wear constant	2.2×10^{-4}	1.3×10^{-4}

Conclusions

- The average friction coefficient and wear constant results in the field are higher than the results from laboratory tests due to the difference in realistic third body.
- The third bodies play an important role in measuring the friction and wear constant which are not possible in the case of a laboratory test.

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Verification of railway multibody simulation models

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Railway vehicle models are commonly used in many research areas, and model verification is highly important part of the model building process. Verification makes the models more functional and improves their reliability. There are various model verification methods, some regulated by different country-related directions or guided by recently updated EN14363 standard, but still giving responsibility to modeler´s own decisions and opinions.

This presentation tells about a research project, which aim was to define a suitable verification method for vehicle models created in Tampere University of Technology (TUT). After completing that, the method was tested in practice by verifying three previously built vehicle models. The selection among different verification methods is mainly based on a few relevant facts: the accuracy of the measurement method, the possibility to repeat the measurement with vehicle models and the suitability of the measurement method for real vehicles.

The chosen verification method was eigenmode analysis, which is performed to both real vehicles and vehicle models. In addition to the overall verification process, this presentation also tells about the observed positive and negative sides of the chosen verification method and the measurements performed to determine the eigenmodes of the real vehicles.

The eigenmode values got at measurements and simulations were compared and based on that comparison the values of vehicle model parameters were improved. The improvement process is iterative and the changes were made as long as the overall results got better or as long as the new suggested parameter value stayed reasonable.

As a result of this survey, TUT vehicle model values in both eigenmode frequencies and damping were clearly improved, which means they are now closer to those measured from the real vehicles. The parameter values were kept in a realistic level, so the changes made to parameter values are acceptable. During the verification, some values were also changed to unfavourable direction. Still, taken as a whole, the function and reliability of the models was improved. In addition to that, plenty of valuable knowledge concerning different verification methods and implementation of verification measurements has been gained.

Vehicle vibrations at the Holmestrandsporten tunnel

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The Holmestrandsporten Tunnel is a 12 km long double track tunnel on the Vestfoldbanen in southern Norway. It was opened for traffic on November 28, 2016. During the first months of 2017 there were reports of vehicle vibrations in the tunnel at speeds above 170 km/h, and on March 10, 2017 a temporary speed reduction to 130 km/h was introduced while the cause of the vibrations was being investigated. As with the reports of vehicle vibrations at the opening of the Swedish Hallandsås tunnel the year before the events attracted a massive media attention.

The Hallandsås vibrations were caused by bogie hunting, Jönsson et al. (2018), and this was also the primary hypothesis for Holmestrandsporten. Measured worn wheel profiles in combination with measured rail profiles gave high equivalent conicities, which strengthened the suspicions. A full-scale test with a Type 74 Flirt trainset at maximum speed 200 km/h was decided, with measurements at two consecutive nights with reprofiling of the wheels in-between. Lateral carbody accelerations from the tests are shown in figure 1. This confirmed the hunting hypothesis. The vibrations could be avoided by reprofiling the wheels and the speed restriction in the tunnel was lifted.

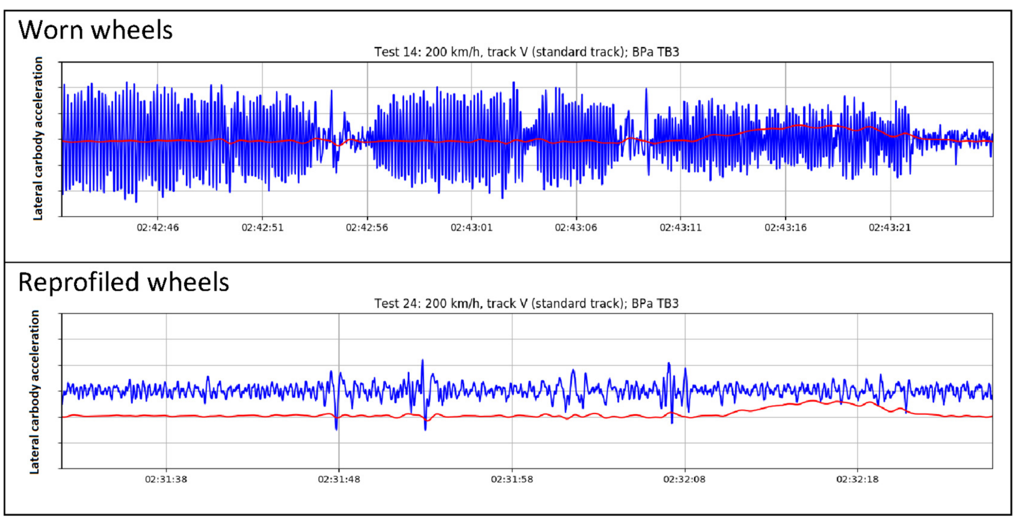

Figure 1 Lateral body accelerations in the Holmestrand tunnel, measured in the same position on two consecutive nights, with worn wheels (upper) and reprofiled wheels (lower).

Acknowledgements

Bane NOR has kindly given permission to presenting this work. Their contribution is gratefully acknowledged.

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Wear-based track access charging an engineering approach

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The European legislation foresees a charging scheme based on so-called direct costs. The main cost portion of those "cost directly incurred as a result of operating a train" is track maintenance (and partly track re-investment cost to be more accurately). The costs of track maintenance is driven by numerous factors, of course, but technically the costs are a result of necessary maintenance jobs to be executed due to specific wear or damage processes. Those processes cannot be described by using "a train run" as indicator, but are direct results of the vehicle-track interaction. Technical vehicle properties - like unsprung mass, traction force applied, bogie design - in combination with operational boundary conditions (speed) and with the line properties (curve radius, more detailed even superstructure and substructure design) lead to different wear and/or damage phenomena that must be restored by maintenance in order to guarantee safety and unrestricted usability. "Direct cost of a train run" is therefore significantly driven by the vehicles in use (and the line properties, of course).

Such considerations seem to be much too complex to be used for the purpose of track access charging, but the overall system cost are influenced by the vehicle-track-interaction massively. If the train operating companies do not have any returns by investing in track-friendly vehicles, they simply will not do it - economically they even must not do it (investing company's money in order to generate savings in another business unit). Cheap(er) vehicles lead to increasing track costs in the overwhelming cases. Those increased costs are distributed to all track user via raised track access charges. This puts pressure on the rail business, so TOCs try to decrease investments in new rolling stock and so forth.

The paper will give an overview of the legal boundary conditions, a possible methodology and the implementation options of such a wear-based, vehicle-specific Track Access Charging scheme using the Swiss example (Wear-Factor Track). Additionally, examples are presented showing the economic consequences of such a TAC-scheme for the infrastructure manager on the one hand, and on the other one for the vehicle operator.

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Sustaining implicit learning in locomotive operation

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Introduction

Modern trains are capable of monitoring health status in real time and infer behaviour of various systems. This trend will grow with advancements of machine learning those will produce feedback for continuously improving the prediction models. Despite reduced physical connectivity of human with locomotive systems, human interference will be required for critical decision-making. Human implicit learning involves the largely unconscious learning of dynamic statistical patterns and features, which leads to the development of tacit knowledge[1]. Pirsig[2] argued that "each machine has its own, unique personality which probably could be defined as the intuitive sum total of everything you know and feel about it". Theses suggest that humans employ an intuitive cognition ability that leads to developing implicit knowledge and interactions with machines. In this study, we focus on signifying the implicit knowledge in locomotive operation context and seek ways to facilitate effective decision-making.

Analysis

We produced three themes by performing qualitative content analysis of the interviews conducted with train drivers. First, train driver is able to perceive operating conditions such as air pressure, current drawn, voltage and engine faults through the driver's console. Secondly, they are also able to comprehend the meanings of faults as console suggests fault type. However, they use experience to greater extent to judge causes and predict consequences. Experienced drivers claim that their physical interactions with the locomotive systems would have made then implicitly aware of many faults, reasons and consequences. For example, they are able to know about air leakage in main compression lines in different contexts, although not able to find and explainable reason for what they come to know. We continue to study the implicit learning opportunities for novice train drivers who have less physical interactions with locomotive systems, but gaining access to richer information through consoles.

Conclusions

Rapid progression in machine learning continue to make inference referring to advanced sensory networks and prediction models. On the other hand, experienced train drivers are gifted with implicit learning abilities through different human sensors that require little deliberate efforts. Limits for future locomotive drivers to implicitly learn is a question. Therefore, it will be important to focus on future design concepts for locomotive consoles and job role; those will support human implicit learning about locomotive system behaviour. This will leverage the benefits of unique human ability, "intuition", at least as long as human do the train driving.

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Co-simulation platform for train-to-ground communications

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Introduction

The project SAFE4RAIL[1] (SAFE architecture for Robust distributed Application Integration in roLling stock) from the Shift2Rail Joint Undertaking will provide a co-simulation platform based on hardware/software co-simulation. The platform will be used for Train-to-Ground (T2G) test environments and the validation of the Train Control Management System (TCMS) transmission over LTE technologies in order to evaluate performances with realistic services and under various railway traffic conditions.

Architecture and Platform

The test environment (shown in Figure 1) for co-simulation combines the use of a discrete-event network simulator (Riverbed Modeler) and a LTE emulator (OpenAirInterface). We evaluate railway services running on a real mobile device (to mimic the MCG equipment). LTE communication is emulated under realistic conditions between the Mobile Communication Gateway (MCG) equipment and the LTE eNodeB/EPC. The backhaul network that interconnects LTE packet gateway to the Ground Communication Gateway (GCG) is implemented under the simulated environment. Various network parameters will be evaluated regarding to their impacts on the railway communication services, e.g., the data rate, the signal coverage, and error rate. Results from the co-simulation reflect measurements from real networks.

Conclusions

We focus on presenting the testing framework as a system-level co-simulation for components of a Train Control Management System (TCMS).

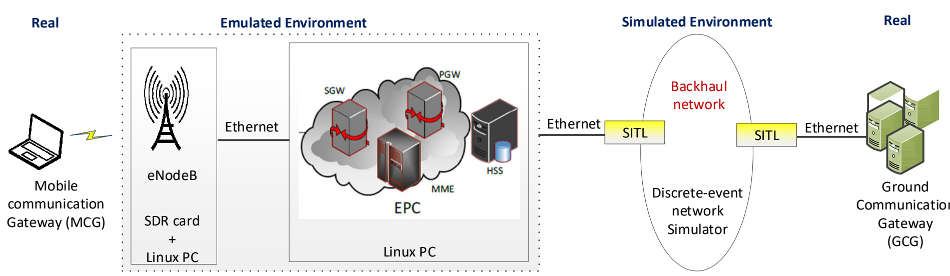

Figure 1 Co-simulation platform for T2G service

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[1]This project has received funding from the Shift2Rail Joint Undertaking under grant agreement No 730830. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme

Improving the quality of railway traffic management systems in Sweden

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Introduction

BOT, ”Beställarens Oberoende Tester”, is a project initiated by the Swedish Transport Administration (TRV) to ensure that the interlocking systems developed by two different suppliers does not have any safety related or operability related issues.

Summary

TRV has contracted an independent party, in this case ÅF Infrastructure AB, to help improve the quality by reviewing the methods, processes and validation activities used by the suppliers as well as TRV.

During the project ÅF have developed a process for BOT to help identify non conformities in the entire development chain for the interlocking. BOT begins by reviewing the documents provided by the suppliers to ensure they are following CENELEC 50126 and 50128 and after that phase is concluded, BOT continues by making a list of focus areas relevant for the specific system release that is currently being reviewed. The focus areas serve as a foundation for the validation activity where BOT reviews the verification activities performed by the suppliers.

During that phase BOT follows a specific function or requirement and reviews how it is verified. If a function is suspected to not be properly tested a deviation report is written and/or a test case is added to a test specification managed by BOT.

Before the release is commissioned BOT spends a couple weeks testing the system trying to find any issues that haven’t been discovered during the verification process done by the suppliers. After the tests are finished BOT writes a “confidence assessment” detailing how the system is regarded which ultimately results in a numerical value related to the overall confidence in the system release.

Since the start BOT has reported deviations regarding several processes and verification activities. Among the deviations reported are requirement tracking of the suppliers, the processes for keeping track of non conformity reports at TRV as well as several issues found during the system tests performed by BOT, some of which have been quite severe.

Monitoring the conditions of switches and crossings/tracks

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Monitoring of track condition is performed by rail infrastructure managers (IMs) using instrumented trains and sometimes using a special train to inspect the track. These geometric quality and track stiffness monitoring systems are not fully applicable to switches and crossings (S&Cs). Hence, a fast and cheap system to continuously monitor the conditions of S&Cs and Tracks is a crucial matter for railway IMs.

A methodology for continuous and real-time inspection of critical track infrastructures, using smart sensor technologies is developed and demonstrated. The system was successfully tested in lab environment and deployed at field test-site, see Figure 1. A train-track interaction simulation tool using the coupled finite element tool ABAQUS and the MBS code Gensys was developed to select suitable sensors architecture and communication, and as a qualitative validation of the system. The architecture of the sensor network developed contains communication platform to transfer data to a remote station in real time to follow up the status and condition of the track being monitored.

Vibration of the rail and the sleepers acceleration has been used as a way to assess the track condition and track quality. Zhao and Wang (2015) measured rail vibrations in transition zone between slab and ballasted track by using acceleration sensors on top of railhead and rail foot above the sleepers. Simulation results of the rail acceleration under certain irregularity and different train speeds indicated that the range and frequency of the rail vibration acceleration is outside the range of the sensors and is not feasible to use as track condition assessment. Hence, sleeper acceleration at the middle and close to the rail seat has been used as a condition monitoring of track infrastructure.

The vertical, longitudinal and lateral accelerations measured at the middle of the sleeper are within the accelerometer range and the signal stood unsaturated. The acceleration signal on sleeper using the new sensor developed is compared with a reference sensor. A good agreement is obtained. The system has a potential for a smart failure and fault detection in rail infrastructure at network level.

Figure 1. Sensors mounted on sleeper at a test site in Munich

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Identification of low-complexity behavioural model for condition monitoring of railway turnouts

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Abstract

Railway networks heavily rely on the dependability of infrastructure components to safely control the train traffic and optimize the network. To reduce operational downtime and minimize the risk of accidents timely maintenance of the railway infrastructure becomes a crucial aspect. Current maintenance policies are mostly periodic and at times reactive; this gives surge to a high O&M cost. Infrastructure maintenance based on reactive and periodic policies is a major cost driver for railway infrastructure managers. Reducing maintenance cost while enhancing asset reliability may be achieved through the adoption of predictive maintenance policies. This requires the availability of a condition monitoring system able to assess the infrastructure health state through diagnosis and prognosis of degradation processes affecting different railway components. Central to condition monitoring systems is the a-priori knowledge of the process to be monitored, either in the form of a mathematical model of variable complexity or signal features/patterns characterizing the healthy behaviour. This study investigates identification of a low-complexity behavioural model of a railway turnout capable of capturing the dominant dynamics associated with the ballast and railpad components. Track accelerations measured during receptance tests performed at different locations along a turnout of the Danish railway infrastructure are utilized together with the Eigensystem Realization Algorithm – a type of subspace identification – to identify a fourth order model of the infrastructure. Since receptance tests are seldom performed by infrastructure managers due to cost and potential disruption of service, we then investigate the use of train induced motion data to drive the identification procedure. The rail acceleration recorded during ordinary train traffic is employed to identify a low complexity behavioural model. Exploiting the measured accelerations the natural frequencies of the ballast and railpad are estimated through an estimation scheme based on empirical mode decomposition and subspace identification. The robustness and predictive capability of the identified models in reproducing track response under different train excitations have been validated using both proposed identification methods. The findings of the current study open for opportunities of plug & play condition monitoring systems of railway turnouts with predictive capabilities.

Condition monitoring of crossing panels using embedded sensors

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This abstract presents a simulation study on condition monitoring of crossing panels performed in EU-project In2Rail. The research question has been whether it is possible to monitor the condition of a crossing panel in terms of track settlements and crossing geometry quality using embedded sensors. To this end a time-domain simulation model for dynamic wheelset-track interaction has been built with a structural representation of the track. As this track model includes structural elements such as rails and sleepers, it is possible to extract and evaluate structural response signal "measurements" from the model. Utilizing this simulation model a two-level factorial design study was performed in order to find correlations between candidate measurement signals and parameters related to the status of the track.

Figure 1 presents the maximum vertical crossing acceleration (normalized by vehicle speed) as a function of the maximum vertical crossing displacement for simulations with varying track and traffic conditions. The figure illustrates the findings in this study that a poor crossing geometry will mostly cause an increase in the recorded maximum crossing acceleration while settlements in terms of for example a void sleeper will mostly be visible in terms of increased vertical crossing displacement.

Based on these results it is proposed that if the maximum vertical acceleration and maximum vertical displacement of a crossing in traffic are recorded over time together with the speed of passing vehicles, it should be possible to determine the status of a given crossing in terms of settlements and crossing geometry degradation from this data.

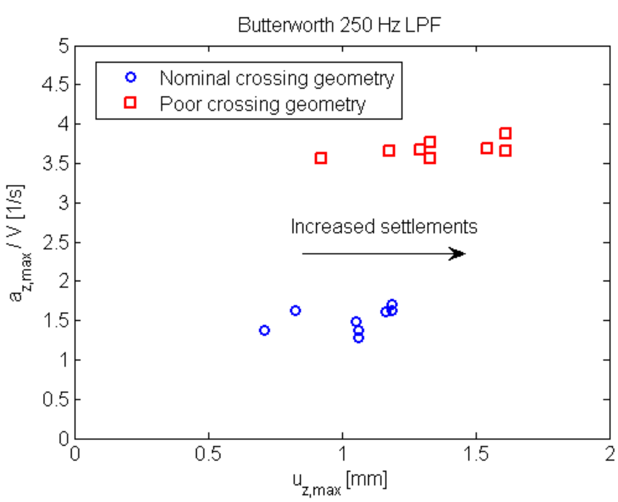

Figure 1. The maximum vertical crossing acceleration (normalized by vehicle speed) plotted as a function of the maximum vertical crossing displacement for wheel passages under varying track and traffic conditions. The maximum values are taken from simulation results that were filtered at 250 Hz using a Butterworth Low Pass Filter.

Train based differential eddy current sensor system for rail fastener detection

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Introduction

One of the crucial component in rail track is the rail fastening system, which acts as a means of fixing rails to sleepers. Manual inspection and two-dimensional visual inspection of fastening systems, have predominantly dominated over the past two decades. However, both these methods have drawbacks when the visibility is obscured. The present article presents the concept of a train based differential eddy current sensor for fastener detection. This paper describes the theoretical background of the sensor system and shows experimental results from field measurements along a heavy haul railway line in Sweden.

The sensor used to detect the fasteners utilizes the eddy current principle, where a varying magnetic field is created over a conducting material for two different excitation frequencies of 18 kHz and 27 kHz. This varying magnetic field induces local circular currents called Eddy currents on the surface of the material, which in turn creates an opposing magnetic field, which are picked up by receiver coils within the sensor. The eddy currents generated on the surface of the material are dependent on the conductivity (μ), permeability (σ) and the geometric form of the material. The pickup coils are differentially coupled, which implies sensitivity only to changes in generated eddy currents in rail and vicinity, not any absolute value can be detected. To investigate the possibility of detecting fasteners, the sensor was mounted 65mm above the railhead on a trolley system and was pushed along the track. Different measurements were conducted along the railway track with healthy track sections with intact E-clip fasteners and were compared with measurements of a track with missing clamps.

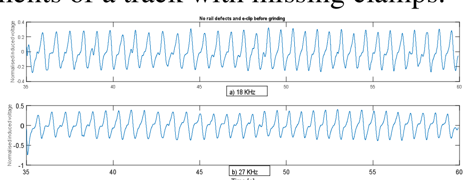

Figure 1 Time signal a) 18kHz b) 27kHz for healthy track with all fasteners intact

Figure 1 shows the time signal of the measurement carried out for a healthy track over 33 sleepers. Individual clamps are easily distinguishable from both 18 kHz and 27 kHz plots. The zero crossing in the signal from the positive to negative values indicates the center positioning of the fastening system for each sleeper.

It can be concluded that the sensor can detect fastener signatures from a distance of 65mm above the railhead. Furthermore, the study shows that missing clamps can be detected by analysing the fastener signatures