Modern railway for pro 21^{st} Century
Proceedings

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Student Scientific Conference

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Guest Editors

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Preface

The Student Scientific Conference in 2021 is a continuation of the student scientific conferences held in previous years: Interoperability in Railway Transport – IRICoN 2016, Modernization on the Railway – IRICoN 2017 and High-Speed Lines – the Future of the Czech Railway – IRICoN 2020.

This year's conference "Modern railway for 21st Century" is focused on modern technologies implemented in railways in the 21st century. The railway has its place in the 21st century. According to a recent study by the International Union of Railways, the rail transport has about four times less external costs per passenger-kilometer than road or air transport. In freight transport, it is even six times less. Meanwhile, more than half of the external costs of road transport come from accidents. For aircraft, the vast majority of externalities are related to exhaust emissions and their impact on climate change.

An important area of modern railways in the 21st century is digitization, which is the main content of the Intelligent Transport Systems on Railways (ITS-R) project and the technological development of ITS-R in the Railways 4.0 project. An important change in today's railways should be the overall digitization, which is not only focused on the area of control, command and signaling, but also on passenger-related areas (internet access, etc.), information and check-in technologies, logistics and dispatcher applications. This involves, above all, the fundamental and systematic coverage of the entire railway by mobile network and to equip all vehicles by new digital technologies. This opens up great opportunities for the railway in the future. However, with the massive shift towards a fully digital railway, new problems have to be solved, such as cyber security or the economic sustainability and efficiency of the railway. Therefore, the topic of ITS-R and Rail 4.0 was one of the main conference sessions.

Of course, the modern railway also affects other parts of railway operations. If we want to operate a really high-quality and reliable railway transport, it is necessary to take care on periodic maintenance of vehicles and especially infrastructure. Freight transport is a major problem; most vehicles are at the end of their lifetime and digitalization of them seems to be difficult and economically disadvantageous. In addition to maintenance, the operation, purchase or lease of vehicles could also be discussed. In addition to electrification, the energy sector is indirectly affected by the backup of independent vehicles to ensure service availability in the event of a power failure.

The professional level of the conference was guaranteed by presentations of leading experts in railway transport from universities and from companies and institutions in railway transport (e.g. SŽ, ČD, VUŽ, VUKV). The main part of the participants were students of master and doctoral study programmes from the Czech Technical University in Prague, Brno University of Technology, University of Pardubice, VŠB-TU Ostrava and University of West Bohemia.

The Student Scientific Conference in 2021 was held under the auspices of the Dean of the Faculty of Transportation Sciences, doc. Ing. Pavel Hrubeš, Ph.D.

Vít Fábera
On behalf of Scientific Committee

Contents

MATHEMATICAL METHODS TO SUPPORT RAILWAY ENERGY SIMULATION

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Abstract. With energy costs continuously rising, evaluating energy intensity of the vehicles is becoming more and more important. Although this issue relates to almost all means of transport, this article focuses on railway vehicles only. Data on vehicle energy intensity can be obtained either from test rides or by simulation. Simulation is undoubtedly less expensive as it does not require actual rides of the real vehicles (costs of energy, wear on the vehicle, traffic restrictions etc). However, it also brings various risks and less accurate results.

In this article, main principles that can eliminate these deviation from the reality will be briefly described. Most of the energy simulation do not consider real vehicle dimensions sufficiently that can impact on the simulation results or on the simulation method itself. Presented calculations were executed by using author's simulation software. Part of the methodology was taken from the previous, already verified, versions of the software for vehicle ride simulation.

Keywords: Accuracy, energy consumption, lineside resistance, simulation.

1. Introduction

Train ride energy simulation need to have more accurate calculations than other kinds of simulations. This is due to the fact the the final energy consumption is affected by multiple factors, both internal and externals. To ensure its sufficient accuracy for calculations, the simulation should have following key characteristics:

- Usage of exact calculation method with through information on the vehicle
- ***Consider railway track and external conditions in its surrounding***
  (meteorological conditions, temperature, humidity etc.)
- Consider real physical dimensions of the vehicle (train)

2. Detailed information on railway track and on meteorological conditions

Detailed information on railway track are essential element of a good simulation. For instance, transition between neighbouring track sections where track profile changes, for example when straight track changes into turning. These transitions ensure smooth train ride. Therefore, lineside resistance between track sections does not change abruptly but gradually. Another important factors that affect vehicles operation are external surrounding conditions (meteorological conditions, temperature, humidity etc.). all these factors have a huge impact on lineside resistance of the vehicle[1].

Considering environmental conditions is essential part of an accurate simulation. In this simulation, environmental conditions were considered only marginally (humidity of the railways tracks). A comprehensive solution of this matter will be presented shortly.

3. Actual vehicle dimensions

Vehicle dimensions (length, width, height, front shape etc.) have huge impact on vehicle ride behavior and this influences energy consumption too, both fuel and electricity (for electric vehicles). In this part, we will focus mostly on vehicle (train) dimensions of length. Apart from considering vehicle only as a mass point, taking length into account will have a significant impact on lineside resistance.

Other vehicle dimensions impact only on driving resistance, especially on the air resistance. In-depth solution of the driving resistance will be presented shortly. Calculations for short vehicles (locomotives, multiple-part trams etc) are likely to have similar deviations as calculations for mass points. However, calculations for long vehicles are likely to give different results and therefore cannot be ignored. This is the reason why this study/ research was conducted.

Solution of this issues is demonstrated in the following example:

- Trains consisting of locomotive series 363 (weight = 87t, length 16, 8m) and six semi-loaded/occupied carriages (type "bdbmsee") with undercarriages (type GP200) with average[1] weight = 45t and length = 26m is moving on the track section (length of

[1] It's calculated with 40t weight of each coach

Figure 1. Locomotive series 363 with six carriages, Source: Author.

the track section = 5000m) at constant speed of 100km/h. Gross vehicle weight is 357t and length is 173m.

- **Picture2** shows lineside resistances for the chosen track section. For more clarity,
- **Picture3** illustrates first 1000m of the track section.
  - ▷ **Blue line** indicates lineside resistance used in the simulation considering train as a mass point. That is the sum of the rail profile resistances (especially gradient resistance, running resistance in train tunnels etc.)
  - ▷ **Red line** ilustrates lineside resistance used in the simulation considering real (nonzero) vehicle lenght and real weight that is evenly distributed.
  Green line shows lineside resistance used in the simulation considering real (nonzero) vehicle length and real weight of its parts (carriages, locomotive).
- Red and Green line are calculated from a blue line (based on the position of the particular train part on the track that is defined by particular lineside resistance). The shape of both lines is determined by the vehicle movement direction (from 0m to 5000m marking). In case of the opposite vehicle movement direction (from 5000m to 0m marking), green and red lines will be different.

To assess the impact of vehicle length on the energy consumption, three train ride simulations were conducted. The simulations analyze train rides on the given track part/ section, each with different lineside resistance. The results are shown in Table1.

4. Conclusion

Simulation calculation with consideration of real vehicle length and relevant weights of certain parts of the vehicle are different from the counterpart simulation using mass point. This difference is approximately 1%. This deviation is not very high and therefore it is understandable that it is often neglected in other

	Electric energy consumption [Wh]	Difference (compared to mass point) [Wh]
"Mass point"	112955	–
Real length, same weights	111998	957
Real length, real weight	111943	1012

Table 1. Simulated electric energy consumption on given track section 5000m, Source: Author.

software. However, in this case, However, for the presented example/calculation, no extreme situations such as long cargo train with considerable heavier carriages were chosen. Therefore the expected deviation for such extreme cases is likely to be higher than 1 %.

The task was completed and new version of the simulation software is even closer to replacing vehicle test rides (train). This leads to financial savings, that cannot yet be quantified within the scope of this article.

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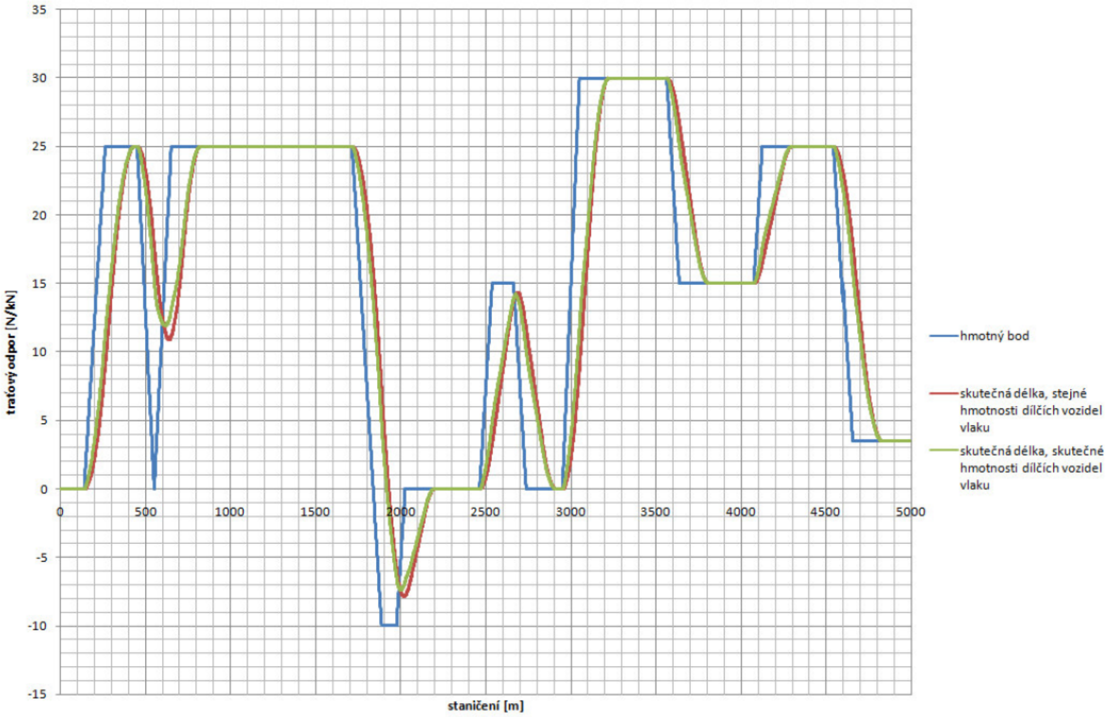

Figure 2. Lineside resistance on the chosen track section (5000m), Source: Author.

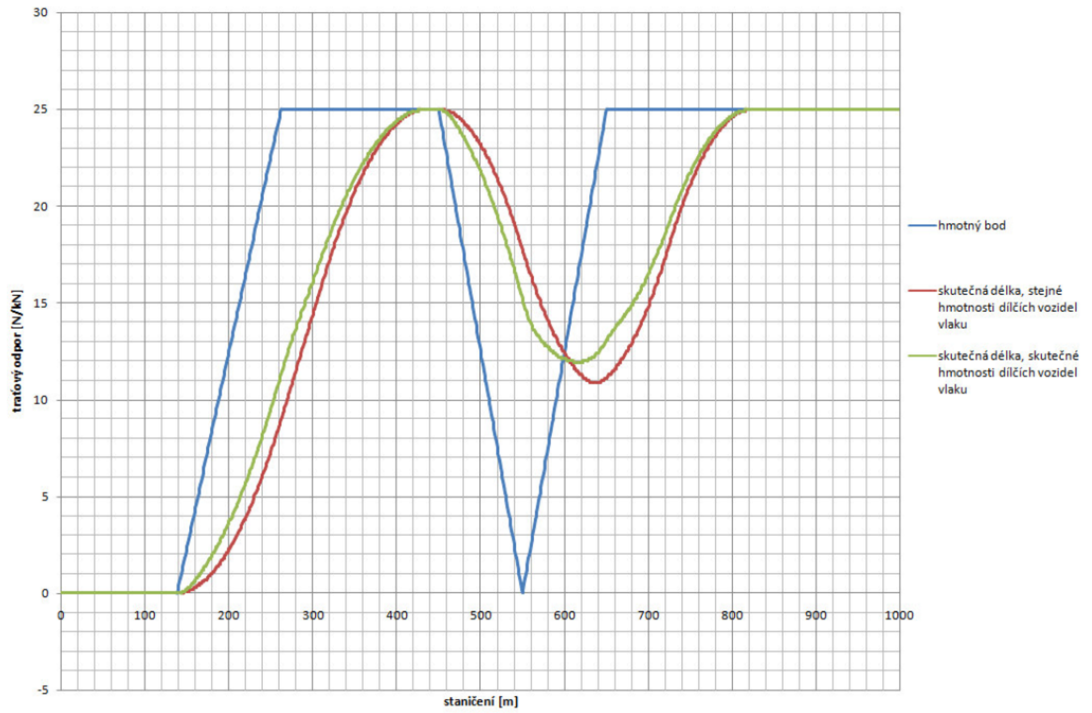

Figure 3. Lineside resistance for the first 1000m of the chosen track, Source: Author.

KALKER'S COEFFICIENT c_{11} AND ITS INFLUENCE ON THE DAMPING AND THE RETUNING OF A MECHANICAL DRIVE TORSION SYSTEM OF A RAILWAY VEHICLE

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Abstract. Within the research of electromagnetically excited torsion oscillations in the mechanical part of traction drive systems of modern railway vehicles, which has been realized at the Faculty of mechanical engineering at the CTU in Prague, there are two separate simulation models in use. The basic calculation model, which is utilized to gain basic characteristics of the torsion system as natural frequencies and natural modes of oscillations. And the complex simulation model, which simulates a drive of the vehicle. This contribution is focused on the basic calculation model, which has been built in MATLAB. This model in its first version did not apply the contact between wheels and rails. It was necessary to find out, if this simplification is relevant with respect to subsequent simulations within the complex simulation model and its results. Therefore, the contact interaction as a traction force in longitudinal direction in the wheel-rail contact was realized via the Kalker's linear theory. This article deals with the comparison between models with and without the implementation of the wheel-rail contact and its influence on the damping within the torsion system and retuning of the torsion system.

Keywords: Kalker, natural frequency, railway vehicle, torsion system, wheel-rail contact.

DIGITAL TRACK MAP FOR THE VEXA EXPERT SYSTEM

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Abstract. This paper aims to summarize possible solutions of a Digital Track Map proposal, designed to become a data source for the VEXA decision-making system. The VEXA project is carried out in cooperation of the Department of Applied Mathematics at the Czech Technical University in Prague – Faculty of Transportation Sciences and the AŽD Praha s.r.o. control and signalling systems supplier. The Digital Track Map is an indispensable data source describing the railway line intended for the VEXA supervised trains operation and its surroundings. Being created in the ArcGIS Pro software environment, the digital map allows individual objects to be visualized and handled as standard GIS features and described by related data stored in a geodatabase. Depending on the object class, the object location can be expressed in different ways. Not only physical location (directly expressible using GIS features) but also functional location (as the objects relate to a particular track) must be considered.

Keywords: Autonomous railway vehicle, Digital Track Map, expert system, GIS, VEXA.

The VEXA expert system itself consists of several interconnected modules providing various functionalities leading to perform the tasks of an autonomous railway vehicle. Based on the evaluation of defined inputs, it aims to substitute decision-making processes of a train driver. These inputs can be outputs from detectors (e.g. obstacle, fire) and status reporting systems (as regards the individual modules) and track condition monitoring. With the use of a knowledge base and decision rules (railway operation rules, decision algorithms taking into account the driver's behavior), VEXA evaluates the conditions for running a railway vehicle in order to grant a permit to start moving or to issue a request to stop the train. The Digital Track Map data represent one of the important inputs for the VEXA system decision making processes.

Even though the Digital Track Map is not a part of VEXA itself, it is being developed in close collaboration with the system in order to provide it with required inputs. Whereas one of the VEXA system goals is to detect unwanted objects around the railway line and especially on the running track, the map serves as a basis for comparison against the scene recognised on the basis of inputs captured by the means of onboard devices. While these inputs are supposed to be processed by the Perception Input Module of the VEXA system, the Map Matching Module is responsible to compare the map with the recognised scene. Subsequently, the relevant outputs are provided to the Incident Analysis Module and possibly further to the Incident Solver Module in order to prevent or deal with the consequences of a possible accident.

Considering the aspect of topological decomposition, the Digital Track Map consists of two subsystems: Digital Map Trackside and Digital Map Onboard. The Digital Map Onboard subsystem comprise the data tiles being loaded from the Digital Map Trackside part depending on the specific train path and works in close collaboration with the Map Matching Module, responsible for further data processing. Selection of individual data tiles to be loaded is based on the knowledge of the vehicle location. The vehicle location is also necessary to be known in order to determine the distance and direction in which the individual objects are located relative to the vehicle. This information is supposed to be provided by the GNSS technology. It can be also determined using an odometry system of a railway vehicle, e.g. using collaboration with some of the automatic train control or automatic train operation systems.

In the foreseeable future, VEXA should be able to receive data from the AVV system, which is the instance of ATO used in the Czech Republic. This system uses the description of the infrastructure to the extent necessary for its purpose in the form of so-called segment profiles. Because there is the possibility to get some infrastructure data directly from ATO, it is not needed to include them to the Digital Track Map. The segment profiles, however, do not contain relevant spatial information. In order to localize the segment profile data in geographic space, it is necessary to link individual segment profiles with appropriate geographically located elements. Such a connection will make it possible to express the location of a point defined by the segment profile identifier and the depth of the segment profile penetration (absolute position from its beginning) also through geographical coordinates. This is essential both in terms of ATO infrastructure data localization and for the purpose of expressing the railway vehicle geographical location based on the odometry information.

Spatial expression of a railway transport route, which is the basis for localization of many infrastructure data description components, can take several different forms. Considering the principles of the UIC RailTopoModel recommendation, the topology of the Digital Track Map network is designed using net elements and net relations. Due to the nature of the task solved, the only possible approach is to use the micro level of detail with linear elements representing individual tracks interconnected by net relations at nodes representing switches. The Digital Track Map, created in the ArcGIS Pro software, allows individual object to be visualized and handled as standard GIS features, i.e. points, lines and areas. Therefore, the RailTopoModel linear element class can be considered as a specialization of the line feature class, in the GIS context. Individual line features are fundamentally linestrings, i.e. sequences of points localized using geographical coordinates which can also have their altitude and stationing defined. In the case of linear elements, these points can be obtained through geodetic survey or by sampling the analytical track description. The aforementioned ATO segments are assumed to be mapped to the net elements defined in this manner, then.

Various types of railway infrastructure objects and properties, according to the RailTopoModel terminology called net entities, can be localized basically in two different ways. The physical location essentially corresponds to the localization with the use of the standard GIS features and expresses the real location of physical objects in geographical space. On the other hand, the functional location expresses the projection of the relevant object into associated point or segment defined within an (in our case linear) element or several (often consecutive) elements. This projection is typically perpendicular but in justified cases may be defined in another way to suit the functional nature of the localized object in relation to the railway transport route. Depending on the method of functional location, we can further distinguish between spot, linear and area location. Not only the railway infrastructure objects and properties but also the objects of the railway surroundings need to be localized in the Digital Track Map. The physical type of location is supposed, in this case.

After the design of its structure is completed, the Digital Track Map is supposed to be first used on the VEXA system trial implementation on the Čížkovice – Obrnice railway line, also known as Švestková dráha. The first testing is planned for the line section between the Libčeves railway station and the Sinutec railway stop. The prospective intention is to extend the technology to a wider range of railway vehicles and parts of the railway network.

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MODERN RAILWAYS FOR THE 21^{st} CENTURY – A CHALLENGE NOT ONLY FOR DESIGNERS

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Abstract. The paper outlines the basic goals for modern rail transport in the Czech Republic. This contribution points out some challenges and technical tasks that designers and operators of the rail transport in Czech Republic will have to deal with if they want to succeed in the conditions of the liberalized European railway market after the year 2035. Moreover, the article assesses the demands placed on safety of the railway transport and presents suggestions for reduction of the consequences of a rolling stock-car collisions in regional transport.

Keywords: Active safety, design vehicles, ETCS, high speed railway, modern railway transport, passive safety, regional railways.

CONSTRUCTION 4.0 IN THE CONCEPT OF THE RAILWAY

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Abstract. The digital and technological innovations that have been developing massively in recent years are often referred to as the 4th Industrial Revolution or Industry 4.0. The construction industry seems to be somewhat on the sidelines. The big topic is BIM (Building Information Modelling), but this is only one component of the contemplated Construction 4.0. Other topics, if not completely neglected, are minimally neglected in the Czech Republic. Yet, and perhaps for this very reason, it is very important to address them.

This article looks at the description of the different elements of the Construction 4.0 concept and their possible application in transport, through the overall digitisation of the railways.

Keywords: Construction 4.0, digitalisation, railway.

RAILWAY TRACK DEFLECTION ANALYSIS BY USING EVOLUTIONARY ALGORITHMS

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Abstract. In contrast to numerical methods, analytical modelling of the railway track is one of the less time-consuming and computationally demanding methods which, in combination with the computing power commonly available today, can form an effective tool for analysing the behaviour of the railway track.

This paper deals with the use of iterative methods of evolutionary algorithms, together with analytical modelling, for the purpose of reverse analysis of the measured deflection caused by moving loads acting on the railway track. The theoretical assumptions of the analytical model used, the data collection methodology and the method used for the reverse analysis are presented. The results of the analysis are also presented.

Keywords: Evolutionary algorithms, railway track deflection, reverse analysis.

ACCIDENT RATE OF REGIONAL RAILWAY VEHICLES AT RAILWAY CROSSINGS FOR THE YEARS 2014 TO 2018

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Abstract. From a societal point of view, there are growing demands to increase traffic safety and reduce the risk of accidents of rail and road vehicles. The research to increase the safety of railway vehicles, which is carried out at the Faculty of Mechanical Engineering of the Czech Technical University in Prague, aims to increase the active and passive safety of railway vehicles. Components and systems of active safety are designed to reduce the risk of an accident. Components and systems of passive safety are designed to minimize the consequences of accidents. One of the parts of the active safety of railway vehicles is the condition and safety of the railway lines on which the railway vehicle is operated. The first part of the article focuses on the evaluation of accident statistics of railway vehicles with other road users at railway crossings for the years 2014 to 2018 with regard to the cause of the accident and the level of security of railway crossings. The conclusion of the article is devoted to proposals for solutions that could lead to a reduction in accidents at railway crossings.

Keywords: Accident, active safety, ETCS, railway crossing, railway vehicle, road vehicle.

Comparison of Selected Parameters for Evaluation of Rail Surface Damage Intensity

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Abstract. This paper deals with the issue of evaluation of a rail surface damage (*RSD*) intensity. Some ways of calculating parameters that represent the *RSD* are described. In this context, a multi-body model of a railway vehicle was created and several simulations of this model on a curved track were performed. Furthermore, these simulations were evaluated and the *RSD* parameters were compared.

Keywords: wheel/rail interaction, rail surface damage, wear number, multi-body simulation.

1. Introduction

In recent years, some railway infrastructure managers have started to use vehicle ratings based on damaging effects of vehicles on tracks. These damaging effects are directly related to maintenance requirements of tracks. One of the damaging effect is the rail surface damage (*RSD*), which occurs when wheels roll on rails. *RSD* primarily represents a wear of rails by abrasion and secondarily a relationship between the wear and a rolling contact fatigue (*RCF*). This method of evaluation may motivate vehicle operators to use and purchase track-friendly vehicles.

This paper is focused on several methods for evaluating *RSD* intensity and these methods are compared. These evaluation methods are described. The parameters that represent *RSD* intensity are compared depending on selected vehicle parameters. By means of multi-body simulations of vehicle running, a quantification of the parameters representing *RSD* intensity and damaging effects can be performed.

2. Rail surface damage

Rolling of wheels on rails is possible due to normal forces acting in wheel/rail contact areas and the existence of adhesion in these contact areas. In general, when wheels rolls on rails, creepages and tangential (creepage) forces occur in the wheel/rail contact areas. This means that the part of the wheel surface moves relative to the rail surface. A consequence of this movement is the wear of the rails and wheels by abrasion. The amount of wear depends on some design parameters of a vehicle, some wheel/rail contact conditions (coefficient of friction/adhesion, materials) and some track parameters.

The rolling contact fatigue (*RCF*) is another damaging effect caused by wheels rolling on rails. *RCF* causes cracks on the rail surface. Under certain conditions, crack initiations can be removed by wear on the rail surface. Thus, the wear can be beneficial in terms of the rolling contact fatigue.

2.1. Wear number

The parameter called the wear number T_γ [Nm/m] is the first option for evaluating and comparing the damaging effects of vehicles that result in *RSD*. This parameter is based on the physical assumption that the wear of the rails and wheels corresponds to the specific friction work performed in the wheel/rail contact. The wear number is defined as:

$$T_\gamma = |T_x \gamma_x| + |T_y \gamma_y| \,, \tag{1}$$

where T [N] is the tangential (creepage) force and $\gamma\,[-]$ is the creepage in the wheel/rail contact. The letters x and y describe the longitudinal and lateral direction of these quantities. Since these quantities (specifically creepages and lateral creepage force) cannot be measured on a real vehicle, it is necessary to determine the value of the wear number using multibody simulations of vehicle running.

The wear number in the form presented in Equation 1 is used in the methodologies of some railway infrastructure managers for setting track usage charges (e.g. methodology [2]).

2.2. Rail surface damage parameter according to EN 14363

Another parameter for the evaluating of the rail surface damage intensity is presented in Annex K of standard EN 14363 [1]. The current indirect evaluation of rail wear in this standard is performed using the quatistatic lateral guiding force $Y_{a,qst}$, which sometimes shows a very weak connection with *RSD*. Therefore, the standard proposes the parameter T_{qst} which is a combined quantity of lateral Y_{qst}, longitudinal $T_{x,qst}$ and vertical Q_{qst} forces acting in the wheel/rail contact and represents the rail surface damage intensity. The parameter T_{qst} is defined as:

$$T_{qst} = \frac{Q_{qst}}{10000} \cdot \left(330 \cdot f^2 - 62 \cdot f + 4\right), \tag{2}$$

where

$$f = \frac{Y_{qst}}{Q_{qst}} + 0,62 \cdot \frac{|T_{x,qst}|}{Q_{qst}}. \tag{3}$$

The constants in these equations are derived as regression parameters from the dependence of T_{qst} and T_γ. The parameter f (Equation 3) is dimensionless then the unit of the parameter T_{qst} (Equation 2) is Newton [N]. This parameter has been defined in order to be able to measure the values of input parameters (forces) on a real vehicle without multi-body simulation.

3. Multi-body simulations

The values of previously defined quantities were obtained from multi-body simulations of running vehicle. For the purposes of this study, the multi-body model of a conventional passenger car of an electric unit was used. The model and multi-body simulations of railway vehicle running were performed using SIMPACK simulation software.

Setting the wheel/rail contact conditions is a very important part of the simulations. The wheel profile ORE S1002 and the rail profile 60E1 were used. The rail inclination of 1:40 was considered. The FASTSIM algorithm was chosen to calculate the tangential (creepage) forces.

The simulations were performed on several curved tracks with a radius from 250 m to 1200 m. The cant and cant deficiency values are constant for all simulations.

4. Simulation results

Time records of the quantities acting in the wheel/rail contact (lateral, longitudinal and vertical forces) and the parameter wear number T_γ were monitored and exported from the multi-body simulations. From these records, the mean values of the quantities in the fully curved part of the tracks were calculated.

The first part of Figure 1 shows comparison of the wear number T_γ and the parameter T_{qst} (calculated according to [1]). For different values of the friction coefficient μ in the wheel/rail contact, the individual curves are plotted as a function of the curve radius R. For all values of the friction coefficient, this chart shows that the values of the parameter T_{qst} are very close in the range of the curve radius from 700 m to 1200 m. As the radius of the curve decreases, the values of the parameter T_{qst} as well as the parameter T_γ values increase.

The second part of Figure 1 shows the difference between the values of the wear number T_γ and the parameter T_{qst}:

$$T_\gamma - T_{qst} \quad [N]. \tag{4}$$

The best match of the parameters occurs for the smallest value of the friction coefficient. As its value increases, the difference between the values of the investigated parameters increases. Around the value of 700 m of the curve radius and the friction coefficient $\mu = 0.6$, the value of the difference is about 100 N. For the same value of the curve radius, the wear number T_γ value is 182 N. This indicates a bad match of these parameters for larger curve radius and higher values of the friction coefficient.

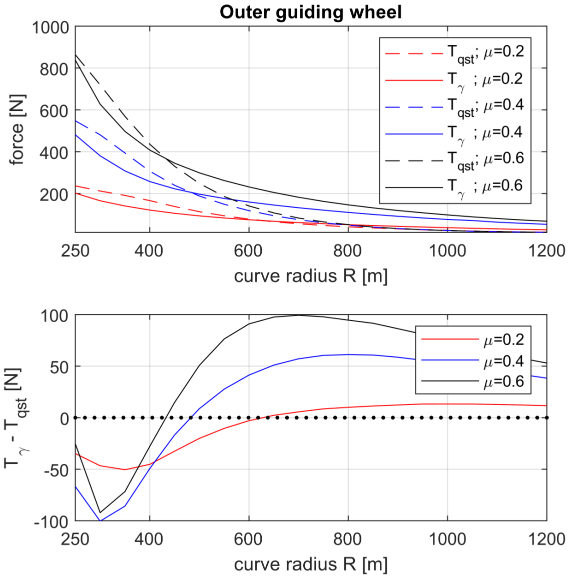

Figure 1. Influence of the curve radius R on the values of the wear number T_γ and the values of the parameter T_{qst} on the outer guiding wheel in the defined range of the friction coefficient μ (first part). Dependence of the difference $T_\gamma - T_{qst}$ on the curve radius R in the defined range of the friction coefficient μ (second part).

5. Conclusions

It can be assumed that the wear number T_γ represents the wheel and rail abrasion wear and indirectly also represents the rolling contact fatigue effects. It is used by railway infrastructure managers as an indicator of damage and maintenance of a curved track. Unfortunately, the wear number must be obtained from multi-body simulations and cannot be measured on a real vehicle.

An alternative quantity is the parameter T_{qst} defined by the standard EN 14363. This parameter shows the same trends as the wear number on the outer guiding wheel. The difference between these parameters increases with a higher value of the friction coefficient. In large radius curves, the parameter T_{qst} has smaller values than the wear number T_γ.

Acknowledgements

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THE LONG-PITCH CORRUGATION DEVELOPMENT IN SMALL RADII CURVES

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Abstract. The paper deals with the phenomenon of long-pitch corrugation in curves of the small radii and also the effects that accelerate or slow down its development. The paper presents data from sections of railway track measured for new rails, rails before and after grinding or replacement. The effect of train speeds running through the curves and the associated cant deficiency or excess were studied. The tendencies of long-pitch corrugation development are described, which can be used to estimate when maintenance action or rail replacement will be necessary.

Keywords: Cant defeciency, cant excess, long-pitch corrugation, speed, track, train.

Various technologies to remove rail defects such as the long-pitch corrugation are present. The spectrum starts with the preventive grinding and spans all the way to a complete replacement of the rails. To understand which technology is for the track section or even for the specific curve at the time the most durable, a broad microgeometry data collection is necessary. Based on the data history it is then possible to predict the further defect development and to lay down the maintenance guidelines in order to improve the possessions plan and to minimize negative effects on the railway operation.

Although there are procedures and methods to measure a microgeometry of rails, in most cases these applications are simplified for practical use in the track record, for compiling substantial amounts of data, or for the "Rail reprofiling reception" [1]. The evaluation for the purposes of the development of the long-pitch corrugation then happens only based on line manager requests.

For the purposes of measuring and monitoring, the defects are categorized according to ČSN EN 13231-3 [1] into four wavelength ranges. Wavelengths in the range $100--300$mm are considered [2] as long-pith corrugation (corrugation primarily on the surface of inner rails in curves).

The categorization mentioned above is not very suitable for the long-pitch corrugation monitoring, hence the length of the waves could be even shorter than 100mm [3, 4], especially in the curves of small radii. Following [5], based on the long-pitch corrugation creation theory, own measurements, and data comparison, it could be concluded, that for the long-pitch corrugation monitoring the range $30--100$mm and the range $100--300$mm may be merged, since wave amplitudes in both ranges usually reach similar or even same values.

Based on the measurements of the actual state there is the possibility to predict the speed of the further development of the long-pitch corrugation in curves of small radii. Simultaneously, there is a possibility by monitoring weighted cant deficiencies (respectively cant excesses) to estimate in advance in which curves the progression of the defect will be faster.

Currently, a spectrum of measures exists to suppress the development of the long-pitch corrugation: starting with the methods aiming to prevent or slow down the defect progression and concluding with the measures designed to remove already developed defects. It is thus possible to use elastically enhanced superstructure or to grind off the defects extensively. That is why infrastructure managers face the difficult decision of which of the methods would be most suitable for their respective cases. Once they had some appropriate tool to predict the defects progression, they can easily, based on the previously conducted measurements, decide for the actions generating lesser expenses or minimize the track possessions.

Performed measurements have also shown, that long-pitch corrugation monitoring via the P2P values is the most suitable way. Assessments have additionally proven, that such monitoring should not be conducted without observation of other factors and parameters as well, hence the long-pitch corrugation is the result of the processes happening in an interconnected system infrastructure – vehicle – traffic. Some parameters change over time very dynamically (rail wear, composition of trains), others are consistent (such as curve radii). Long-term monitoring shows, that even in sections, appearing for the first sight as homogeneous, where unified construction and parameters take place, still some anomalies are present with different properties. These could be not only of the construction type (like the superstructure composition), but also even historical (previous actions not just to the infrastructure itself, but to the entire system infrastructure – vehicle – track). That amplifies the need for the selection of the appropriate parameters for the monitoring.

Regarding the current state, where the tracks are regularly diagnosed by the track recording car for the superstructure, there is no lack of high-quality data. In the case of the national line corridors, this means consistently three times during one year to obtain such data. Naturally therefore there should be the drive to assess the data not only for the backward analysis but also for the defect development prediction. In the modern era, where powerful hardware and neural networks are present, data analysis is even easier.

There is also the need for defect progression prediction on the designer side. The current state of the general knowledge of track designers is not overly broad: the usual conclusion is that the usage of curves of small radii is wrong, and it will eventually lead to long-pitch corrugation development. This is the space, where quality information about the parameters affecting the progression of long-pitch corrugation could be used most. Track designers like to use guidelines and therefore some kind of a handbook, where the significant parameters, superstructure choices, and other crucial aspects would be summarised, would eventually lead to a significant decrease in the construction and maintenance costs and also in the number of possessions.

As a result, society would obtain superior, safer, more dependable, and a neighbourly conscious railway track.

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Comprehensive Verification of the Behavior of the Continuous Welded Rail on the Bridge

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Abstract. The aim of this paper is to verify the real behavior of the continuous welded rail on the bridge with a longer expansion length than allowed by Czech national regulations. Special attention is focused to the rate of interaction of the continuous welded rail and the bridge, which decisively affects the stress state in the continuous welded rail when the temperature changes. In order to improve the result and increase the accuracy of observation, two measurement methods (geodetic and strain gauge) were chosen while recording the temperature conditions of individual components of the system were simultaneously recorded.

Keywords: continuous welded rail, longitudinal resistance, thermal expansivity.

1. Introduction

When designing new bridge structures with a continuous welded rail, it is very appropriate to avoid of a solution with expansion devices (or rail joints) in the track in the track for several reasons. This is primarily a benefit about of passenger comfort in the case of exclusion crossing of these problem areas, a significant reduction in dynamic effects in transition zone and reduce maintenance costs. Especially when replacing the permanent way on current bridge structures and in adjacent sections of a track is also the need to take into account the financial benefit of establishing a continuous welded rail in compared to the variant with expansion devices whose acquisition costs are several fold higher than the costs for a solution with an uninterrupted running edge of the rails. On the other hand the elimination of expansion devices in the bridge zone involve increased of stress in terms of the combined response of the structure and track to be deal with the issue in the design. From the designer's point of view, however, the current standard provisions may appear as insufficient, especially with regard to the variability of the permanent way system and bridge structures and it happens that certainty is taken into account compromise precautions in the calculations. In aspect of infrastructure serviceability of the continuous welded rail is considered the most important the spacial track stability. Its uses on bridges has drawback, therefore it is necessary to take into account in specially the span of bridge structures and loads that affect the interacting system.

This work solves especially the first part of the problem, which is continuous welded rail and its role in the interaction system with a bridge. It focused particularly on the range of its dependence on a bridge structure movements and phenomena that occur when the state of the whole system changes. The design of the bridge structure and its characteristics deals only marginally, but tries to describe in detail its behavior, especially when temperature conditions changes.

A number of research projects focus on determining the combined response of the bridge structure and continuous welded rail from individual types of additional stresses in the rails, which are:

- stress from thermal changes in rails,
- stress from thermal changes in bridge structure,
- stress from traction and braking forces,
- stress from classified vertical traffic loads.

The effects of the temperature changes of the continuous welded rail and the bridge structure were recorded on a five-track bridge at the Břeclav railway station. The total length of the supporting structure is 80,3 m and consists of an orthotropic structure with the overhead bridge deck, supported by longitudinal beams. Track skeleton monitored track with deep trackbed is composed of rails 49 E1 on concrete sleepers B 91S/2 with elastic fastening W 14. This bridge significantly exceeds its expansion length requirements set by national regulation S 3 part XII by 20 m.

2. Methods

The whole experiment was divided into two phases, which took place independently of each other:

- PHASE I: Geodetic measurements of the position of the bridge structure and continuous welded rail based on geodetic monitoring of bridge structure displacement and continuous welded rail depending on temperature changes.

- PHASE II: Tensometric measurements of the stress state of the continuous welded rail based on monitoring the stress state continuous welded rail by strain gauges depending on temperature changes.

2.1. PHASE I: Geodetic measurements of the position of the bridge structure and continuous welded rail

The method of geodetic monitoring with simultaneous measurement of air, rail and bridge temperature was chosen to monitoring the movement of the bridge structure and the continuous welded rail.

The following was monitored on the bridge structure in Phase I:

- displacement of rail strings depending on rail temperature,
- displacement of the bridge load-bearing structure NK1 depending on its temperature.

The first step was to select the location of the measuring points, marked on both rail strings a total of 20 measuring profiles (20 points on the left and right rail string, numbered 1 to 20 against the direction of stationing). For monitoring displacements of the bridge structure 8 points were fitted (marked M1 to M8 - points M1 and M8 were located on abutments, other points on the bridge deck in bridge piers areas).

For monitoring the expansion behavior of the bridge structure and the permanent way depending on the temperature changes were marked observed points in selected cross-section profiles of rail strings whose positional changes in the direction of the track axis were measured in stages, together with the monitoring of other factors (especially the temperature of the rails and the bridge structure). Their stabilization was accomplished a mild hole ϕ 1 mm punched out on the outer unmoved edge of the rail heads. These points were numbered and color marked on the rail web. Applies to both rail strings.

2.2. PHASE II: Tensometric measurements of the stress state of the continuous welded rail

The aim of Phase II was to supplement the geodetic monitoring of bridge and track displacements with knowledge in terms of the stress state of the continuous welded rail. During seven continuous measuring cycles, when one cycle always lasted for 3-4 days, data were collected from the installed ones resistance strain gauges and temperature sensors. Recording period of continuously measured quantities was 1 second.

In Phase II, data were collected from installed resistance strain gauges and temperature sensors about:

- relative deformation of rail strings depending on temperature change,
- temperature of the bridge structure and continuous welded rail.

From the data obtained from the individual phases, it was necessary to approximate the set of measured data by the given equation so that the approximation function was best matched to the measured data. Using force of the Matlab program, the parametric space was searched, which was discretized and seeks the optimum of the function on it. It was necessary to determine the size of the error that occurred during approximation. This was done by calculating the residue, which the sum was minimized to estimate the parameter of the regression function.

3. Results

The resulting coefficient of thermal longitudinal expansion of the bridge structure, based on geodetic measurements and mathematical linear approximations using least square method, was determined by the value:

$$\boldsymbol{\alpha_m = 9,66 \cdot 10^{-6}}\,\mathrm{K}^{-1}$$

Looking into recent experimental research (for example experimental measurements on the Znojmo viaduct or on the bridge in Kolín) it can be stated that for these three steel structures with a rail bed the bridge structures are comparable and very similar in terms of the determined equivalent coefficient of thermal expansion of the bridge structure (Znojmo – $\alpha_m = 9,7 \cdot 10^{-6}\,\mathrm{K}^{-1}$, Kolín – $\alpha_m = 8,5\ a\ 8,9 \cdot 10^{-6}\,\mathrm{K}^{-1}$).

The resulting longitudinal resistance of the track on the bridge without loading by rail traffic, based on geodetic measurements of the position of the rail strings and mathematical general linear approximation using least square method, was determined by the value:

$$\boldsymbol{k_{\mathrm{ip}} = 4,5 \cdot 10^3}\,\mathrm{N.m}^{-1}$$

Based on tensometric measurements of the relative deformation of the left rail string and temperature measurements of the bridge structure and the track, it was found that there was a good agreement with the results obtained by geodetic measurements. By tensometric measurement of the left rail string and mathematical general linear approximation using least square method, was found the value of longitudinal shear resistance of the track on the bridge without load by rail traffic of the size:

$$\boldsymbol{k_{\mathrm{ip}} = 4,6 \cdot 10^3}\,\mathrm{N.m}^{-1}$$

4. Conclusions

It is apparent that the resulting values from both phases are in area of very low values of longitudinal shear resistance of the track. That is to say, the tension in the rails due to thermal expansion of bridge structure is much less affected than might be expected. This is evident by the fact that the track on the bridge, with an expansion length of more than 20 m longer than permitted by national regulation SŽDC S 3 in the relevant Part XII, does not show, more than ten years of operation, anomalies in the behavior of continuous welded rail and there are no defects on permanent way of a greater extent than anywhere else on the line.

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