The Fifth International Conference on Railway Technology
RAILWAYS 2022
22–25 August 2022
Montpellier, France

Proceedings of the Fifth International Conference on
Railway Technology:
Research, Development and Maintenance
Edited by J. Pombo
Civil-Comp Conferences, Volume 1, Paper 21.12
Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.1.21.12

On the surface parameterization of wheels and rails with defects for vehicle-track dynamic analysis

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Abstract

Wheel and rails develop localized defects on their surfaces that play a key role in the vehicle-track interaction. The impact of these defects on railway assets can be cheaply investigated by developing adequate multibody simulations. A series of measured profiles are required to model both wheel and rail, however, the accuracy of the wheel-rail contact forces depends not only on the number of measured profiles, but also on the robustness of the parameterization method of the wheel and rail surfaces. This paper aims to study wheel and rail surface parameterization methodologies that require minimum measurements for realistic vehicle-track interaction studies. A wheel with idealized defects on the tread and flange back is considered in this work from which the number of measured profiles is varied. In turn, different parameterization schemes are used, namely splines and shape preserving polynomials and parameterized and non-parameterized profiles are utilized. This work highlights the advantages and disadvantages of increasing the number of profiles, depending on the parameterization method.

Keywords: Wheel-rail contact, Wheel defect, Rail defects, Surface parameterization, Experimental measurements.

1 Introduction

The vehicle-track interaction is key in railway dynamics in which the high wheel-rail contact forces lead to several degradation mechanisms like wheel flats [1]. Hence, wheels and rails with defects tend to amplify the vehicle-track interaction forces deteriorating other railway components from both the vehicle and infrastructure.

Multibody software packages allow simulating vehicles negotiating a railway track at specified operating conditions that are of interest to determine the origin and consequences of a certain defect. Here, wheel-rail contact force models are of great importance to determine accurately and efficiently the vehicle-track forces [2]. Most of the wheel-rail contact models assume an elastic approach, allowing the local deformation of the contacting bodies which is computed through the virtual penetration between both surfaces, from which the contact patch and creepage conditions are determined to predict the normal and creep forces [3], [4].

In the case of wheel and rail defects, advanced contact models are required to handle wheel and rail with variable profiles [5], [6]. Therefore, a key ingredient is the parameterization of the wheel and rail surfaces that lead to realistic wheel-rail contact forces. In this case, the wheel and rails are often represented by a series of measured profiles defined around the wheel axis and along the rail path, respectively, that are interpolated for a continuous surface representation.

This work investigates different interpolation schemes that realistically represent the wheel and rail surface with defects for different sets of wheel and rail profiles. As a demonstration case, an idealized wheel with defects on the tread and flange back is considered.

2 Methods

Most of the multibody codes developed for railway dynamics require a series of profiles as input to represent wheels and rails with variable cross-section [6]. These profiles are obtained either from a CAD model or digital measurement. Both wheel and rail surfaces are parameterized through a three-dimensional interpolation scheme as shown in Figure 1, which depicts a rail with variable cross-section.

One of the main steps is to identify section break planes [5], i.e. positions at which two consecutive profiles show an abrupt variation in shape. A section break plane delimits two consecutive longitudinal segments. At these section break planes, an ‘additional profile’ is defined by trimming the ‘widest profile’ so that a perfect match exists with the ‘shortest profile’ where they overlap as exemplified in Figure 1.

Two section breaks delimitate a longitudinal segment in which precomputed longitudinal polynomials allow interpolating the wheel and rail cross-sections during the multibody simulation. Each longitudinal polynomial is defined as $u(s)$ and $f(s)$, where s represents the rail length or the wheel angular position, while u and f are the lateral and vertical coordinates of the profiles, respectively.

At each integration step of the multibody simulation, wheel and rail profiles are interpolated through the longitudinal polynomials at the coordinate *s*, where the contact occurs, leading to a set of points defined by *u* and *f*. Here, the profiles can be interpolated trough transversal polynomials defined as *f*(*u*), which is the most used option [6], or by parameterised polynomials defined as *f*(*t*) and *u*(*t*), where *t* is a coordinate that goes along the arclength of the profile. Note that parameterizing a profile as *f*(*u*) leads to constraints when defining the profiles since each lateral coordinate can only be associated to a unique vertical coordinate, thus, vertical faces, for instance, cannot be modelled. On the other hand, parameterizing profiles with *f*(*t*) and *u*(*t*) makes the formulation more complex which leads to a higher computational cost. The advantages and disadvantages of using these two strategies are briefly addressed in this work.

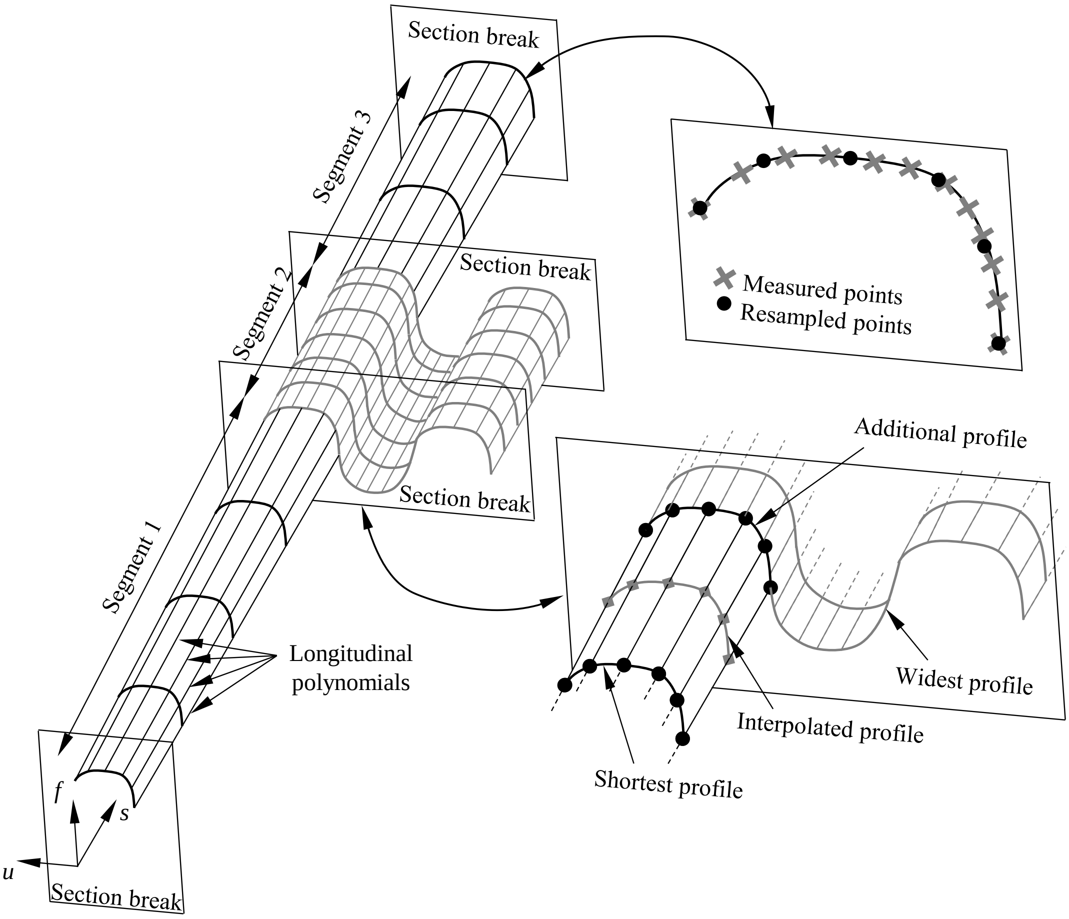
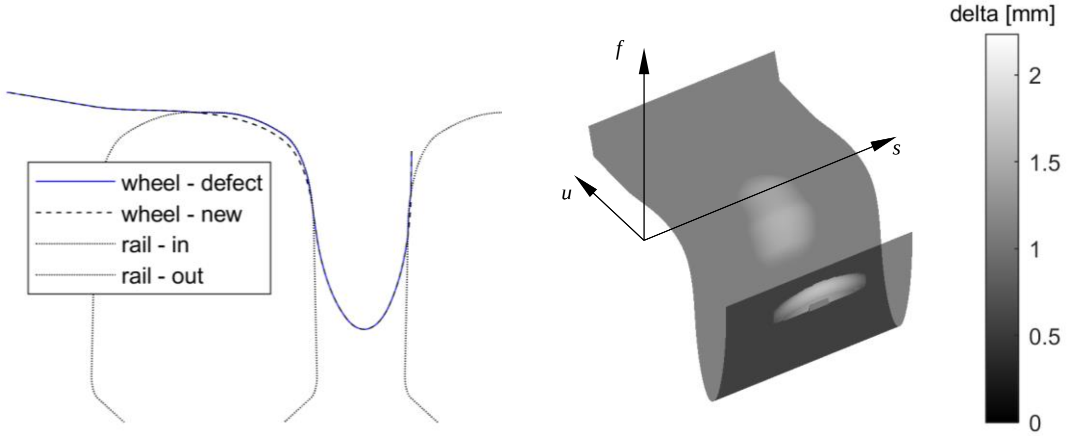


Figure 1: Surface with variable cross-section described by a series of profiles that are fully parameterized using longitudinal polynomials [7].

3 Results

Two defects on the wheel surface are idealized by cutting the wheel with the “rail - in” and “rail - out” profiles as shown in Figure 2(a), leading to the removed material in the tread and flange back. Figure 2(b) shows the wheel surface around the angular position between 170º<s<190º, which contains the defects, and “delta” quantifies the material removed radially with respect to the idealized wheel.



(a) (b)

Figure 2: (a) Wheel and rail profiles at s=180º. (b) 3D surface of the wheel with defect at 170º<s<190º.

The number of profiles to describe the wheel with the defects and the surface parameterization scheme are varied as follows. Two domains are defined for the wheel, the “Defect” part that is defined as 170º<s<190º and the “Nominal” part which comprise the rest of the domain. The number of profiles for the “Defect” and “Nominal” domains are n_D and n_N, respectively, noting that profiles are defined with equal spacing. The values selected are n_D={10,50} and n_N={35,350}, covering cases with different measurement times and tools, such as the 3D scanner and MiniProf®. Regarding the interpolation scheme, the longitudinal and transversal polynomials are obtained with cubic splines or piecewise shape preserving polynomials (Shape P.). The transversal profiles are interpolated with non-parameterized polynomial $f(u)$ or with parameterized polynomials $f(t)$ and $u(t)$. Figure 3 shows the results for the 16 variations and the colour bar represents the radial deviation between the interpolated surface and the idealized wheel with defects.

The higher deviations reach values over 10 mm when considering spline interpolation and n_N=35. Although cubic spline interpolation ensures continuity up to the 2nd derivative, the distribution of profiles over the angular position leads to higher deviation where the wheel has no defect. For the remaining cases, deviations are lower than 2 mm. A potential problem might appear when using n_N=350 as a high frequency oscillation is observed in the defect domain, which can lead to unrealistic high frequency contact forces. Shape preserving interpolation shows less oscillation, however, the continuity of 2nd derivative is not ensured, which can be problematic if the wheel-rail contact force model depends on this quantity. The parametric interpolation does not show a great impact in these results, however, for cases where vertical faces are observed, they are required to enable the surface parameterization.

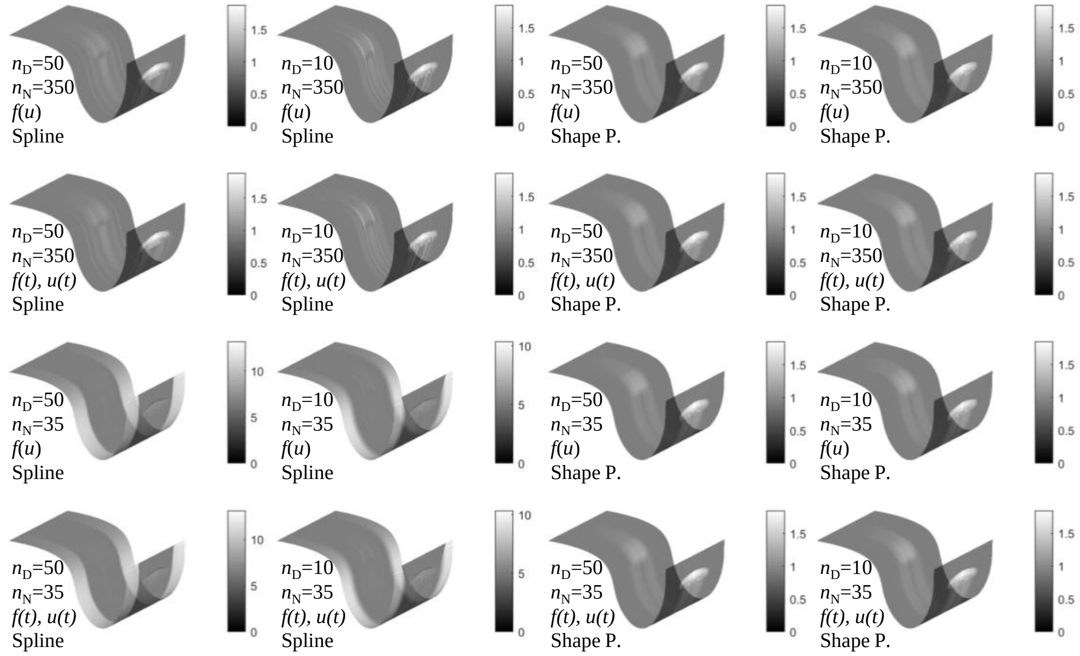


Figure 3: Radial deviation in mm for the range 170º<s<190º between the idealized wheel with the wheel interpolation.

4 Conclusions and Contributions

This paper highlights the importance of the wheel and rail surface parameterization for wheel-rail contact modelling in the context of multibody simulations. The number of profiles as well as the parameterization methods are investigated in this work for an idealized wheel with defects on the tread and flange back. It is shown that the selection of the surface parameterization scheme must be adjusted for the considered input profiles. This work contributes to a gap identified in the International Benchmark on the multibody simulations with switches and crossings [6] in which the surface interpolation method of rails with variable cross-section has a great impact on the computation of wheel-rail contact forces. This work recommends studying the proposed interpolation schemes implemented in a multibody code to identify their impact on the vehicle-track interactions.

Acknowledgements

This work is supported by Portuguese Foundation for Science and Technology (FCT) with the reference projects UIDB/04436/2020 and UIDP/04436/2020 and through IDMEC, under LAETA, project UIDB/50022/2020.

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