A novel approach to estimate wheel-rail contact forces considering wheel flats and out-of-roundness

Filipe Marques[1], Hugo Magalhães[2]

[1]CMEMS-UMinho, LABBELS
Departamento de Engenharia Mecânica,
Universidade do Minho,
Campus de Azurém, Guimarães 4804-533, Portugal
fmarques@dem.uminho.pt

[2]IDMEC, Instituto Superior Técnico,
Universidade de Lisboa,
Av. Rovisco Pais, 1, 1049-001, Lisboa Portugal
hugomagalhaes@tecnico.ulisboa.pt

EXTENDED ABSTRACT

1 Introduction

The vehicle-track interaction plays a key role in railway dynamics, since the wheel-rail forces developed on that interaction are responsible for supporting and guiding the vehicle. However, the existence of high wheel-rail contact forces or abnormal contact conditions typically leads to several surface degradation mechanisms like wheel flats [1]. Hence, wheels and rails with defects on their contacting geometries tend to amplify the vehicle-track interaction forces deteriorating other railway components from both the vehicle and infrastructure.

Multibody system dynamics methodologies allow simulating vehicles negotiating a given railway track at specified operating conditions, which can be of interest to determine the causes and consequences of certain defects. In these studies, the computation of wheel-rail contact forces is fundamental to accurately and efficiently analyze the vehicle's dynamic response, but it is even more relevant for assessing the development of degradation phenomena, such wear, rolling contact fatigue or plastic deformation [2]. In order to solve the contact problem, it is necessary to deal with three fundamental steps, namely, defining the contact geometries, performing the contact search, and calculating the normal and tangential loads.

Generally, 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. In the case of modeling surface defects, the parameterization of wheel and rail surfaces is a key ingredient to achieve an accurate representation of the defect zone, thus, a suitable parametrization scheme and an adequate number of profiles must be selected [3]. Hence, the contact detection process will be affected by the correctness of that previous step, and the complexity of the defects' geometries might compromise the efficiency on the determination of contact shape. Regarding the wheel-rail contact force models, both elastic and constraint approaches can be adopted. However, most of them utilizes the elastic method, 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 [4,5]. It must be noted that more advanced contact models are required to handle wheel and rail with variable profiles [6].

This work proposes a methodology to deal with the contact detection between rails with constant profile and variable wheels with flats and out-of-roundness in order to take into account the wheel defects on the vehicle's dynamic response.

2 Contact Modeling

In this work, both wheel and rail potential contacting surfaces are parametrized, as represented in Figure 1(a). The rails are considered to have a constant profile, which varies along the lateral coordinate u_r. Thus, their surfaces can be obtained through the sweep of their cross-section along a given path, their position and orientation are given as function of the longitudinal coordinate, s_r. In turn, the wheels are considered to have variable profile, thus, several profiles are defined for different angular coordinates, s_w. Each of these profiles is defined along their lateral coordinate, u_w.

A point on the rail surface is easily defined by a pair of coordinates, s_r and u_r, and its location is found by placing the constant rail profile on that s_r location and then, the interpolate its position u_r on the profile. However, for the wheel surface, a more complex strategy is needed due to its surface variability. The set of profiles that define the wheel are grouped in different sections, which are delimited by section breaks. As a preprocessing step, the profiles within each section are resampled to have the same number of points, which are used to compute polynomials along the angular direction, allowing the interpolation of the wheel cross-section for any s_w position at each step of the multibody simulation [3,6].

The existence of wheel defects does not allow to take advantage of its roundness and, therefore, speed up the contact detection process [7]. Bearing that in mind, it is searched the location of the rail path, s_r, closest to the wheel, and the rail is considered to be locally straight, which is a suitable assumption since the rail curvature is neglectable along its longitudinal direction. Then, the wheel is divided into strips, and the contact is evaluated between each strip and that straight rail, as depicted in Figure 1(b). To save computational power, only strips located in the neighborhood of potential contact zones are considered at each step. With this methodology, it is obtained the virtual penetration for each strip along the contact patch which allows a better characterization of the effective contact area and apply a non-Hertzian contact force model [5].

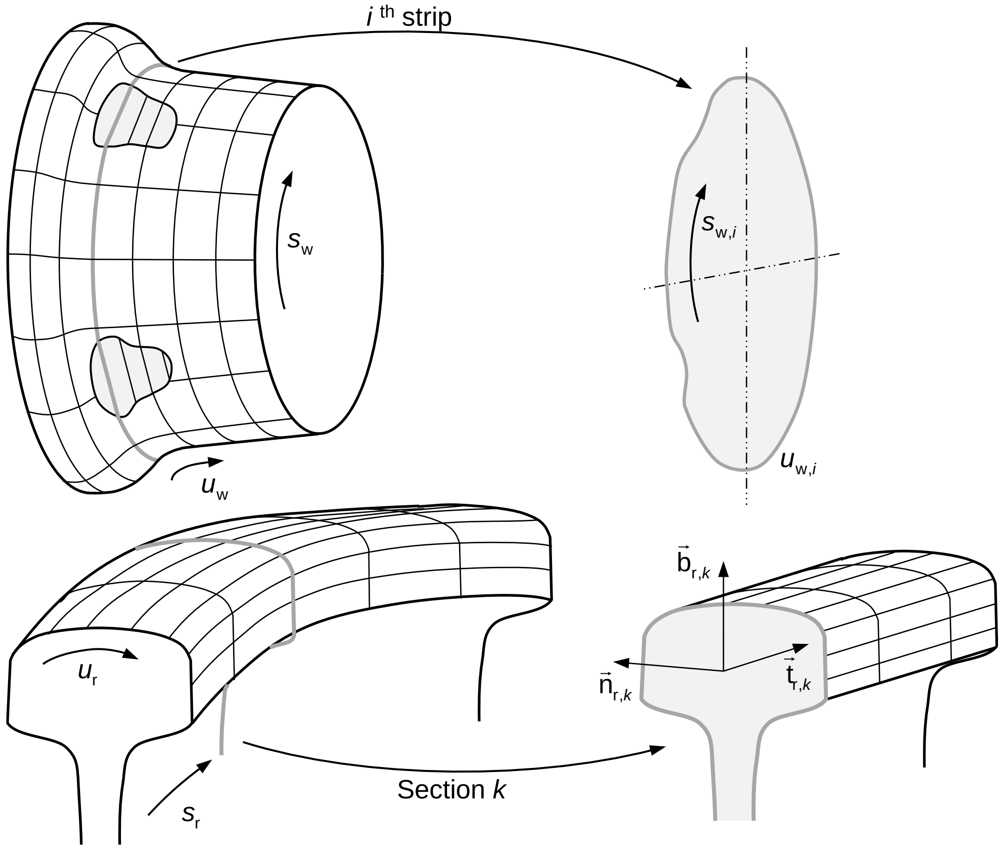

Figure 1: Representation of (a) wheel and rail surfaces parametrization including wheel defects, and (b) interaction between wheel strip and locally straight rail.

3 Application Case

The proposed methodology is applied to a running scenario in which one wheel of the vehicle is defective, while the remaining ones are ideal. The defect is artificially manufactured by cutting the wheel with a rail profile, which leads to material removal in the tread and transition zone. Further studies must be performed to completely assess and validate the methodology.

Acknowledgments

This work has been supported by Portuguese Foundation for Science and Technology, under the national support to R&D units grant, with the reference project UIDB/04436/2020 and UIDP/04436/2020, as well as through IDMEC, under LAETA, project UIDB/50022/2020.

References

[1] L. Jing, Z. Liu and K. Liu. A mathematically-based study of the random wheel-rail contact irregularity by wheel out-of-roundness. Vehicle System Dynamics, 60(1):335-370, 2022.

[2] A. Ekberg, B. Åkesson and E. Kabo. Wheel/rail rolling contact fatigue - Probe, predict, prevent. Wear, 314(1-2):2-12, 2014.

[3] H. Magalhães, F. Marques, J. Pombo and J. Ambrósio. On the surface parameterization of wheels and rails with defects for vehicle-track dynamic analysis. Proceedings of The Fifth International Conference on Railway Technology: Research, Development and Maintenance. Montpellier, France, 2022.

[4] S.Z. Meymand, A. Keylin and M. Ahmadian. A survey of wheel-rail contact models for rail vehicles. Vehicle System Dynamics, 54(3):386-428, 2016.

[5] H. Magalhães, F. Marques, B. Liu, P. Antunes, J. Pombo, P. Flores, J. Ambrósio, J. Piotrowski and S. Bruni. Implementation of a non-Hertzian contact model for railway dynamic application (2020) Multibody System Dynamics, 48 (1), pp. 41-78.

[6] H. Magalhaes, F. Marques, P. Antunes, P. Flores, J. Pombo, J. Ambrósio, A. Qazi, M. Sebes, H. Yin and Y Bezin. Wheel-rail contact models in the presence of switches and crossings. Vehicle System Dynamics, 2022.

[7] F. Marques, H. Magalhães, J. Pombo, J. Ambrósio and P. Flores. A three-dimensional approach for contact detection between realistic wheel and rail surfaces for improved railway dynamic analysis. Mechanism and Machine Theory, 149:103825, 2020.