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Influence of Hertzian and non-Hertzian contact models on two-point wheel/rail contact in different planes

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Abstract

In this work, Hertzian and non-Hertzian approaches are studied and compared for the computation of wheel/rail normal contact in terms of global dynamics solutions. Hunt-Crossley force model is used for the Hertzian contact model and Kik-Piotrowski model is used for non-Hertzian contact method. Due to its good balance between accuracy and simplicity, Polach method is used for the calculation of tangential forces. The effect of wheelset yaw motion on the Hertzian and non-Hertzian contact behaviour is the focus in this work.

Keywords: Kik-Piotrowski model, yaw angle, Hunt-Crossley force model, normal contact force, Manchester wagon 1

1 Introduction

The modelling of wheel-rail interaction plays an essential role in multibody dynamic simulation of railway vehicles. Robust solutions of the contact problem with efficient computational analysis are of great interest for the research community. Due to the simplicity of the implementation and efficient computation, Hertzian contact theory [1] has been widely used for the calculation of wheel/rail normal contact forces. However, this approach is under the assumption that the bodies in contact behave like infinite half-spaces and the wheel/rail surface curvatures at the contact area are constant. Since the curvatures of the wheel and rail profiles are often not constant in the contact area, the wheel-rail contact problem needs to be treated as a non-Hertzian contact.

Active research to compare Hertzian and non-Hertzian contact method for the multibody simulation of railroad vehicles is ongoing. Liu and Bruni [2] compared both wheel/rail contact models for the calculation of normal contact forces in multibody co-simulation. In this line, both normal contact models are compared in [3] to give the insight of proper selection of the parameters to achieve better computational accuracy and efficiency. It is concluded that the non-Hertzian Kik-Piotrowski (KP) [4] method for normal contact with the Kalker book of tables for non-Hertzian contact (KBTNH) for tangential contact led to better accuracy with acceptable efficiency, compared to the conventional Hertzian contact models.
Previously, Burgelman et al. [5] analysed different non-Hertzian methods in rail vehicle dynamics with using co-simulation technique between commercial software VI-Rail and MATLAB. Expanding on this research line, the objective of this work is to compare the influence of Hertzian and non-Hertzian contact models [3] on two-point wheel/rail contact phenomenon in different planes. See Fig. 1.

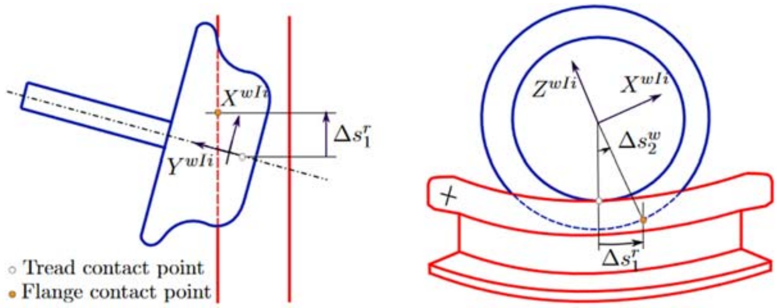


Figure 1: Two points of contact in different planes when yaw angle is not trivial. Lead contact in the right wheel.

2 Methods

In this work, an online contact detection method is used to determine potential contact points on the wheel surface and rail head. The contact detection for each pair of contact point is addressed using the minimum distance calculation between two surfaces. The concave region and the conformal contact are not considered during the detection procedure [4]. As shown in Fig. 2, the directions of normal vector $\mathbf{n}^{wi}$ and $\mathbf{n}^{rp}$ of two potential contacting points from wheel/rail surfaces are the same and identical to the connecting distance vector $\mathbf{d}$ of the two points. Four nonlinear equations are solved to obtain four surface parameters as follows [4].

$$\mathbf{C}(s_1^w, s_2^w, s_1^r, s_2^r) = \begin{bmatrix} \mathbf{t}_1^{wi,T}\mathbf{d} \\ \mathbf{t}_2^{wi,T}\mathbf{d} \\ \mathbf{t}_1^{wi,T}\mathbf{n}^{rp} \\ \mathbf{t}_2^{wi,T}\mathbf{n}^{rp} \end{bmatrix} = \mathbf{0} \tag{1}$$

where the distance vector $\mathbf{d}$ is computed based on the position vectors of the potential contact points on wheel surface and rail head, $\mathbf{t}_1^{wi}$ and $\mathbf{t}_2^{wi}$ are tangential vectors at the contact point on wheel surface, $\mathbf{n}^{rp}$ is the normal vector at the contact point on rail head, s_1^w and s_2^w are transverse and angular wheel surface parameters, and s_1^r and s_2^r are longitudinal and transverse rail surface parameters, respectively. Those four surface parameters need to be solved for from the above nonlinear equations. In addition, Eq. (1) can be applied to solve the potential contact points at wheel tread and flange surfaces independently, especially when two points of contact occur in different planes. See lead contact on the right wheel occurs Fig. 1.

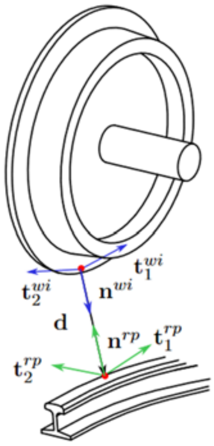


Figure 2: Illustration of the one pair of potential contact points on rail/wheel surfaces with closest distance present common normal directions

Both Hertzian and non-Hertzian contact methods are applied and compared for the computation of wheel/rail normal contact forces in this work. Hunt-Crossley force model [6] is used for the Hertzian contact model and Kik-Piotrowski model [4] is used for non-Hertzian contact method.

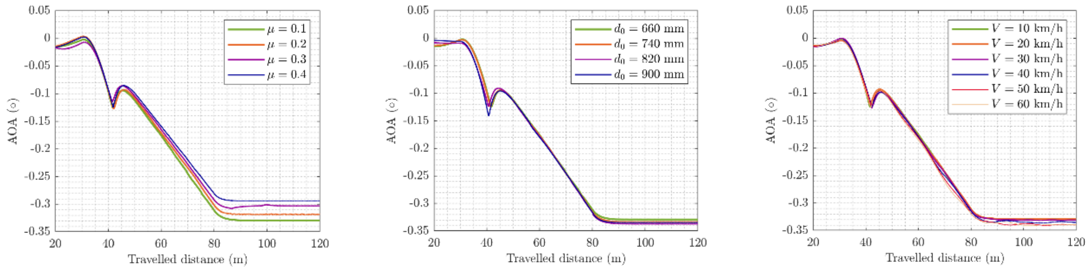
Once the wheel/rail contact point location and the normal contact forces are known, the penetration depth, contact angle and the local radii of curvature of wheel/rail surfaces can be obtained. Furthermore, the relative velocities (creepages) of the contact points on the wheels with respect to the rails can be calculated according to wheelset forward velocities. In the end, Polach method [7] is used for the calculation of tangential forces, due to its good balance between accuracy and simplicity.

3 Results

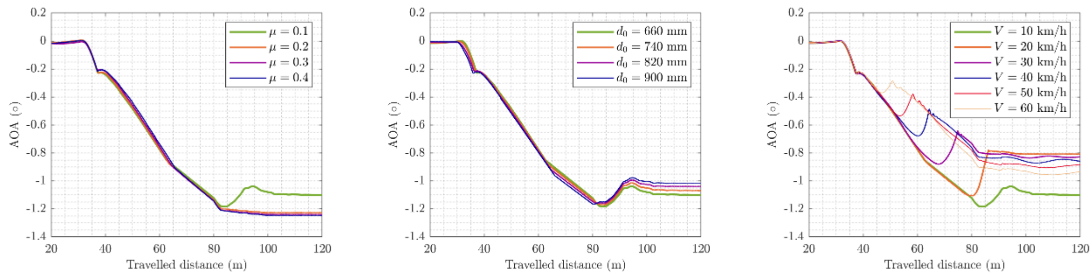
In all case studies, the multibody model of the Manchester wagon [8] is implemented in Matlab environment. The fixed-step-size integrator Adam-Bashforth-Moulton (ABM) [9] with time step size $\Delta t = 0.5$ ms is used. The wheel and rail profiles are the S1002 wheel and LB140-Area rail profiles, which present a unique two-point contact scenario in the tread-flange transition. The primary and secondary suspension parameters are given in [8].

The vehicle is simulated at a constant forward velocity, on a 120 m track without irregularities formed by the following three segments: a 30 m tangent, a 50 m transition, and a 40 m left curve of $R = 450$ m and $R = 100$ m radius segments. Figures 3-4 compare the angle of attack (AOA) and rail surface parameter Δs_1^r associated with lead flange contact point at the outer rail. Different forward velocities $V = 10, 20, 30, 40, 50, 60$ km/h, coefficients of friction $\mu = 0.1, 0.2, 0.3, 0.4$ and wheel nominal diameter $d_0 = 660, 740, 820, 900$ mm are considered in the case study. The wheel/rail normal contact force is computed based on Hertzian approach with the Hertzian contact stiffness at both tread and flange $K_{hertz} = 3 \cdot 10^{10}\ \mathrm{N/m^{1.5}}$.

Figure 3 compares the AOA in the time domain. When the vehicle is at the steady state curving condition (travelled distance from 80 m to 120 m), the coefficient of friction μ is the major factor to affect the AOA for the bigger curve R =450 m. However, for narrow curve R = 100 m case, forward velocity V = 10 km/h results in bigger AOA.



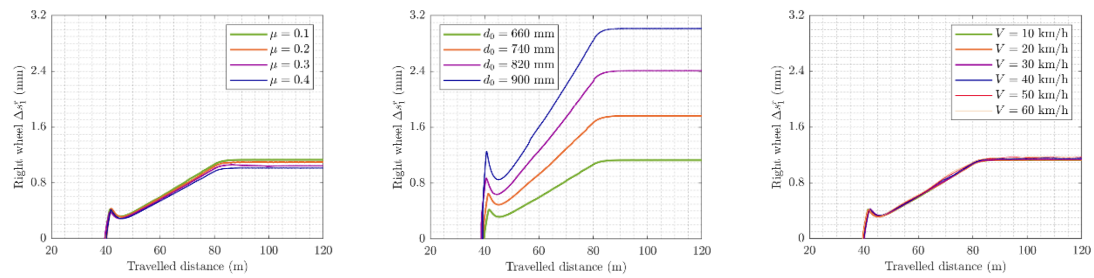
(a) Curve R=450 m (b) Curve R=450 m (c) Curve R=450 m



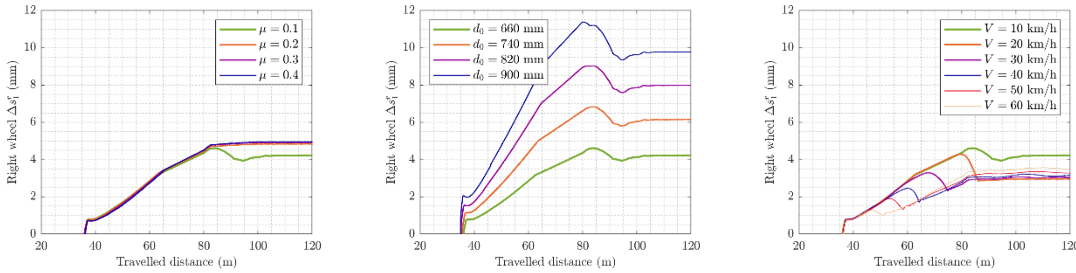
(d) Curve R=100 m (e) Curve R=100 m (f) Curve R=100 m

Figure 3: Comparison of AOA of the leading wheelset when vehicle negotiate different radius curve. (a, d) Time domain with different coefficient of friction μ. Forward velocity is V = 10 km/h and wheel nominal diameter is d_0 = 660 mm; (b, e) Time domain with different wheel nominal diameter d_0. Coefficient of friction is μ = 0.1 and forward velocity is V = 10 km/h; (c, f) Time domain with different forward velocities V. Coefficient of friction is μ = 0.1 and wheel nominal diameter is d_0 = 660 mm.

Figure 4 compares the relative surface parameters Δs_1^r of the leading wheelset in the time domain. It proves that the contact detection algorithm based on Eq. (1) can find the contact point on the flange surface that is in a plane different from that of the tread contact point. See Fig. 1. It is evident that bigger wheel nominal diameter and smaller track curve lead to bigger arc length Δs_1^r.



(a) Curve R=450 m (b) Curve R=450 m (c) Curve R=450 m



(d) Curve R=100 m (e) Curve R=100 m (f) Curve R=100 m

Figure 4: Comparison of the relative surface parameters Δs_1^r of the leading wheelset when vehicle negotiate different radius curve. The other information is the same as Fig. 3.

4 Conclusions and Contributions

Hertzian and non-Hertzian wheel/rail normal contact methods for the vehicle dynamic simulation were studied in terms of global dynamics solutions using the Manchester wagon 1. The effect of wheelset yaw motion on the Hertzian and non-Hertzian contact behaviour is considered in this work.

Currently, only the results from Hertzian contact model are present in this work. The results show that lead-lag contact effect happens when vehicle negotiating very narrow curves at very low velocities following a quasi-static motion.

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