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Flexible Wheelset Models in Dynamic Interaction with Track

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Micro Abstract
Until now, multibody models of vehicle-track interaction mainly use rigid components. In order to improve these models, it seems necessary to include flexible components by coupling finite element analysis with multibody dynamics simulations. The main objective of this study is to present the methodology used to take into account wheelset flexibility in a multibody model of train. Wheel-rail contact forces obtained with rigid wheelset and flexible wheelset are compared.

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Introduction

Since the 19th century and with the development of the railway industry, several authors have tried to understand the wheel-rail interaction, especially contact forces and contact shape. In 1882, Hertz proposed the first theory of the mechanical contacts [4], it was adopted for the resolution of normal wheel-rail contact problem. In this theory, the shape of the wheel-rail contact is assumed to be elliptical without friction. In addition to the Hertz theory, Carter [2] solved, in 1926, the rolling contact problem by taking into account friction and by modeling the wheel with a cylinder and the rail with a semi-infinite plane. Nevertheless, this theory considers only longitudinal creepage. Different authors have extended this theory to other configurations: Johnson [5] in 1958 for longitudinal and transversal creepage with circular contact shape, Haines-Ollerton [3] in 1963 and Vermeulen-Jonhson [8] in 1964 for elliptical contact shape. More recently, with the development of computer capacity, wheel-rail interaction problem were solved by using finite element method (Vo and al. [9] in 2014, Arslan and al. [1] in 2012, Zefeng and al. [10] in 2011, etc.). Nevertheless, high computational cost is the main drawback of these simulations even if only just a small part of the rail ($\leq 1m$) is considered. In order to study the rolling over kilometers, multibody models of vehicle-track interaction used by railway companies mainly use rigid components, allowing real time calculations in low frequency ranges, but these models do not properly estimate the real interaction forces because of the strong hypothesis of the components rigidity. To improve these models, it's necessary to include a maximum of flexible components by coupling finite elements analysis with the multibody dynamics simulations, and by using model reduction methods in order to reduce calculation time. The main objective of this study is to present the methodology used to integrate wheelset flexibility in a multibody train model. To estimate the efficiency of this method, wheel-rail contact forces obtained with rigid wheelset and flexible wheelset are compared.

1 Railway wheelset

The wheelset is the most important and critical component of the railway vehicles, a conventional wheelset is composed of two conical wheels connected by an axle (Figure 1). Based on Kalker's

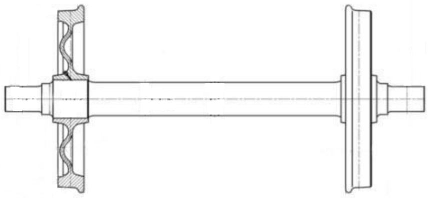

Figure 1. Railway wheelset.

Figure 2. ZTER vehicle and its model in SIMPACK.

linear theory [6], simplified equations of motion of a wheelset with a conical wheels are given by:

$$m\ddot{y} + \frac{2abGC_{22}}{V}(\dot{y}(1+\frac{\lambda}{a_w}) - V\psi) + 2Gab\sqrt{ab}C_{23}\frac{\dot{\psi}}{V} + W_a\frac{\lambda y}{a_w} = F_{sy} \tag{1}$$

$$I_x\ddot{\psi} + I_y\frac{V\lambda}{r_0 a_w}\dot{y} + \frac{2a_w GabC_{11}}{r_0}\lambda y - \frac{2Gab}{V}(\sqrt{ab}C_{23}(\dot{y}(1+\frac{r_0\lambda}{a_w}) - V\psi) - \dot{\psi}(a_w^2 C_{11} + C_{33})) - a_w\lambda W_a = M_{sz} \tag{2}$$

Where a and b are the semi axis of Hertzian elliptical contact [4], V the wheelset velocity, m wheelset mass, G shear modulus of the wheel material, λ the conicity of wheels, a_w the wheelset gauge, W_a the wheelset weight, r_0 the equilibrium rolling radius, C_{ij} the Kalker coefficients [6], F_{sy} and M_{sz} the suspension forces, I_x and I_y the moments of inertia about x and y axis respectively, and y and ψ the wheelset lateral and yaw degrees of freedom (DOF) respectively.

2 Multibody model of railway vehicle with flexible wheelsets

SIMPACK software is used to develop a multibody model of ZTER vehicle (Figure 2). ZTER is a French regional passenger train, operated by the French national railways company (SNCF). The wheelsets are linked to the bogies by primary suspensions, and the bogies are linked to the carbody by secondary suspensions.

To integrate the flexibility of wheelsets, ABAQUS finite elements code is used to develop a finite elements model of wheelset. The eigenmodes of unconstrained wheelset are extracted (Figure 3).

In order to couple finite elements model with the multibody dynamics model, the Craig-Chang method [7] is used to reduce the finite elements model, by retaining some nodes and some of their DOFs (Bearing nodes and contact nodes distributed on the rolling surface of the wheels).

The dynamic behavior of a flexible wheelset is assumed to be described by the following equation:

$$M\ddot{S} + KS = F \tag{3}$$

Where M is the mass matrix, K is the stiffness matrix, F is the external forces applied on wheelset and S are DOFs of the flexible wheelset.

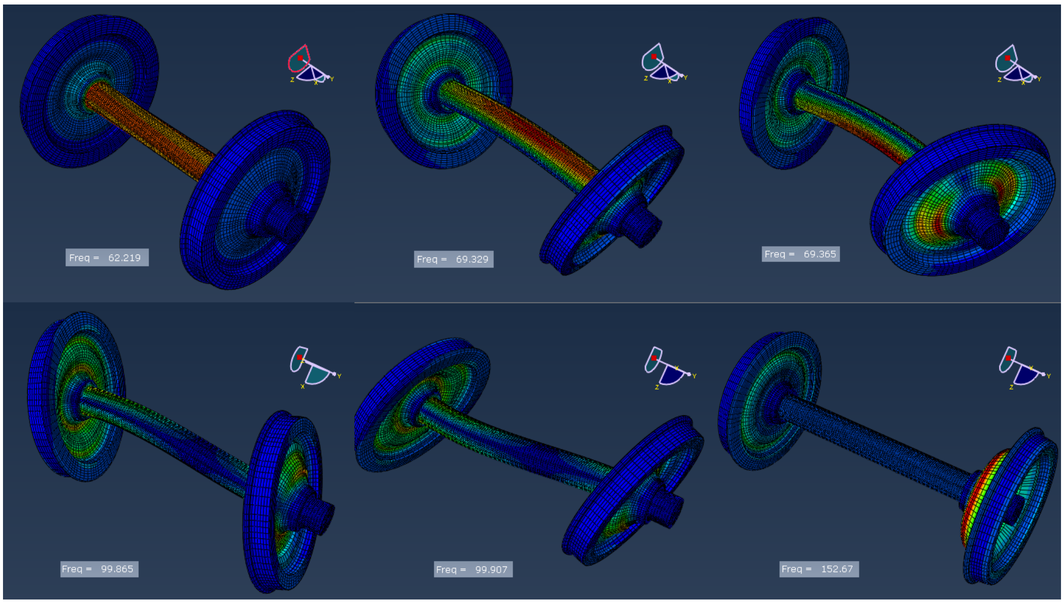

Figure 3. 6 Firsts eigenmodes of unconstrained wheelset.

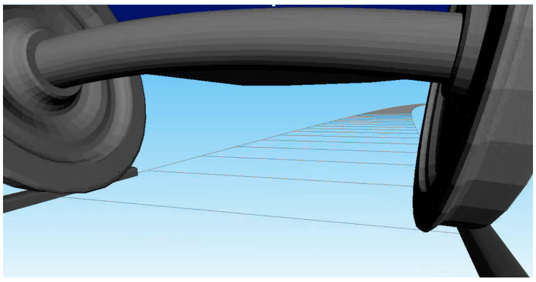

Figure 4. wheelset flexibility.

The relation between the vector of retained DOFs S_r and the wheelset DOFs S is as follows:

$$S = PS_r \tag{4}$$

Where P is the transformation matrix

And finally, the equation of motion of the reduced model can be written as:

$$P^T MP\ddot{S}_r + P^T KPS_r = P^T F \tag{5}$$

3 Analysis of contact forces

Figure 4 depicts the wheelset deformations while the train is running at a speed of $100km/h$ on a straight track. A comparison between the predicted normal and lateral contact forces from the rigid wheelset model and those predicted from the flexible wheelset model is illustrated in Figure 5. It should be noticed that this comparison is related to the forces on the right wheel of the first wheelset. It clearly shows that the predicted forces from the rigid wheelset model are constant while the ones predicted from the flexible wheelset model are oscillating due to the wheelset initial deformation. The oscillation frequency is exactly the wheelset rotation frequency $(9.61Hz)$

Conclusions

The coupling between the multibody model and the finite elements model was carried out in ordre to take into account the flexibility of the wheelsets. With the wheelsets flexibility taken

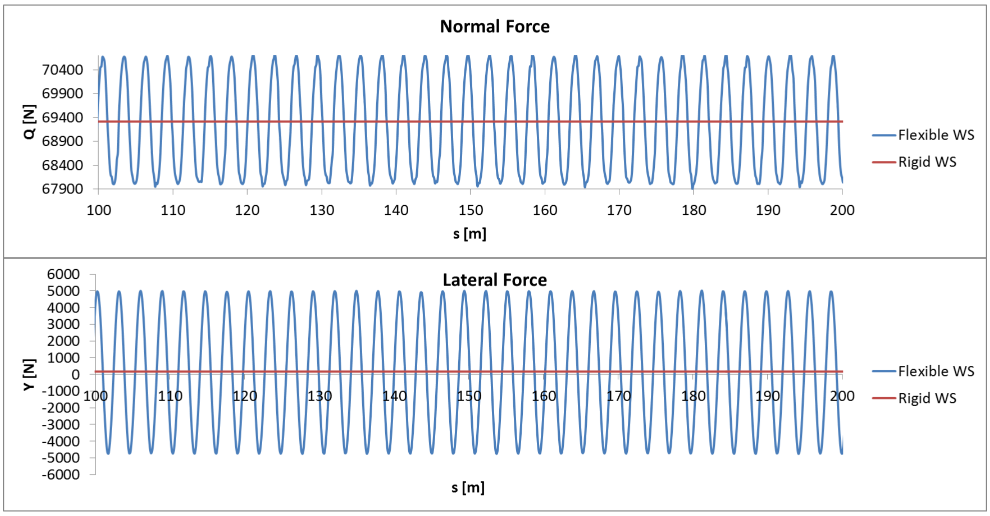

Figure 5. contact forces.

into account, the wheel-rail contact forces prediction is improved compared to the rigid wheelsets model. With flexible wheelsets rolling on a straight track without irregularities, the contact forces are oscillating with a frequency equal to the wheelset rotation frequency, while these forces remain constant when the wheelsets are rigid. The oscillations exhibited by the forces from the flexible wheelsets model come from the wheelsets initial deformation due to the vehicle weight. These results prove that the flexibility of components like wheelsets and rails should be taken into account.

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