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Dynamic Effect of Hollow-Worn Wheels for Freight Rail Vehicles in a Consist

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Abstract

The evaluation of long train dynamics involves different research topics such as optimization of numerical models with a large number of degrees of freedom, modelling of friction, constitutional laws of connecting elements, numeric simulation, among others. Besides those generic requisites, other particular details of typical applications of freight rail car modelling must be addressed such as wheels wear, misalignment of vehicle components, breakage of suspension system, asymmetry distribution of loads, uneven braking etc... Additional modelling difficulty is added when considering all the previous aspects associated also to dynamics simulations. This way, the goal of the work is to present a systematic to analyse the dynamic effects of worn and new wheels, on a convoy freight car and a freight rail car duo, using a multibody modelling software platform. Coupling longitudinal forces are calculated from an efficient draft gear model under a typical operational speed profile in a Brazilian railroad with curves and irregularities. The risk of derailment and the wheel surface geometric alteration is evaluated, and also other operational parameters the freight rail car, that may be used to minimize vibration, noise and track maintenance. The work also shows comparative results of the derailment coefficient Y/Q and wear index on the conditions of new wheels and tread and flange with hollow defects.

Keywords: Railway Vehicle Dynamic, Train Longitudinal Forces, Wear of Railway Wheels, Stability of Railway Vehicles.

1 Introduction

Dynamic performance of freight vehicles is of great interest for rail engineers and researchers. Numerical models of the dynamics of long trains, with many components, are comprised of a large number of degrees of freedom, which require significant computational effort in time. Some strategies are thus necessary, to optimize the dynamic models that analyse the safety of the operation of trains in real scenarios, like stability and curve negotiation performance.

Real cases such as the effect of the worn wheels in rail cars have been studied in different scenarios. Salehia et al. [1] presented the effect of wheels with worn flange on a passenger rail car based in experimental data. Pardhan et al. [2] found that higher temperature, the softening of the rail-wheel material increases the rate of wheel wear of a passenger rail car under real condition as the speed profile, braking force, and contact parameters.

All these studies were developed disregarding the longitudinal forces between vehicles in a convoy. Models with coupled dynamics (lateral-vertical) have already been addressed in the works of [3,4,5,6]. In, Bosso et al. [3], particularly, a long train model was built to evaluate the longitudinal dynamic of train and behavior of some vehicles running on curve. Later, Bosso et al. [4] developed a new Longitudinal Train Dynamics (LTD) code to take the most advantage of the vector logic and matrix management of MATLAB environment. Wu et al. [5] studied the effects of braking for LTD, adding the model of the draft gear apparatus in rail cars. Huang et al. [6] concluded that the dynamic performance of a single car model is about 15% superior to the train model considering the coupler forces.

Therefore, the dynamic effects of worn wheel on a consist are of great interest, since it is a better approximation to real conditions. In the present work, a freight rail car pair subjected to longitudinal and lateral dynamics with typical worn wheel profiles in a Brazilian railroad track is built in SIMPACK. Draft gear model is imported from MATLAB/Simulink via MatSIM, where the Simulink solver calculated actively the longitudinal forces. Speed profiles are adopted for each car of the consist by an LTD code implemented in MATLAB/Simulink and exported to a convoy-coupled model run in SIMPACK. The purpose of this study is to evaluate the dynamic response in terms of safety and wheel wear, compared to the original wheel design.

2 Methods

A particular GDE freight rail vehicle with two Ride Control bogies is modelled, based on a real vehicle, in the multibody dynamic software SIMPACK. The four-axle vehicle consists of a pair of three-piece bogies, with primary and secondary suspension systems adding up to 11 bodies. The 62 DOF load vehicle is used to assemble a couple, with two equal vehicles connected by a fixed coupler, as illustrated in Figure 1. The twin couple is connected to the rest of the convoy, with coupler with 11mm of slack.

Coupler force models with and without slack are imported from MATLAB/Simulink as performed by Wu et al. [7] and described in Eckert et al. [8] to the twin couple model in SIMPACK via MatSIM.

The twin couple is at the end of a convoy formed by 2 DASH9 locomotives + 170 wagons (85 couples). The track is created from real geometric parameters of the Brazilian Railroad and consists of a tangent of 4km, followed by two curves with a radius of 312.5m each, spiral transitions of 61.7m, 52mm of superelevation with asymmetrical vertical and lateral irregularity on each rail, corresponding to the PSD of the European standard ERRI B176 [9].



Figure 1: GDE-Ride Control wagon pair.

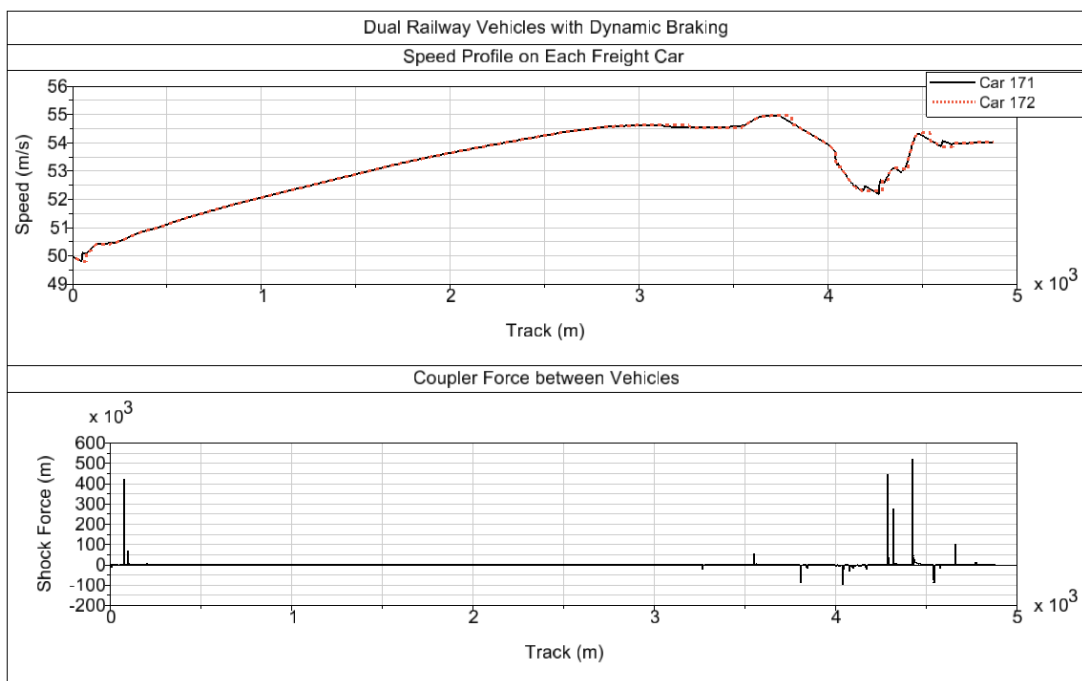


Figure 2: Speed profiles and coupler force.

The speed profile was obtained from the simulator developed in MATLAB/Simulink, whose modelling is described in [8]. The profile has an initial acceleration and then dynamic braking is applied as it enters the first corner. The speed profile on each vehicle is illustrated in Figure 2.

Figure 2 also shows the shock force on the coupler, positioned between the vehicles. The first peak of 400kN, occurs at the beginning of the route and represents the pulling force required to overcome inertia. After the 3.5km position, a speed variation is observed, which, consequently, generates a variation of efforts in the coupler. When reaching the 3.7km position, the dynamic brake is applied to the twin couple, which represents a compression of the Coupler. After the 4.25km point, the couple accelerates again generating a maximum tractive force of 450-520kN.

The worn wheel profiles are from hollow wheels measured from samples of Vitoria-Minas railroad, as shown in Figure 3. Wear regime, according to the function presented by the University of Sheffield [10] is mild with 0.45N/mm^2 . The rail profile used is a worn TR-68, with rail can 1:40. Discrete elastic contact type is used in the simulation where the FASTSIM method is set to determinate the tangential forces of Rail-Wheel contact [2,11].

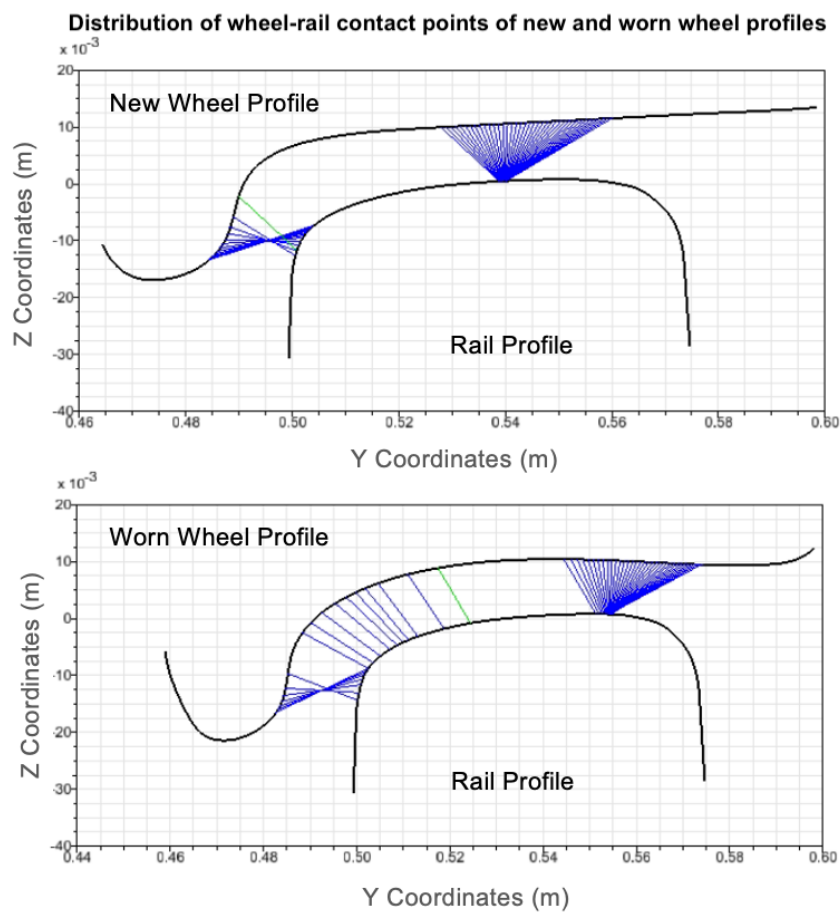


Figure 3: Wheel-Rail contact.

3 Results

Figure 4 shows a comparison of derailment coefficient Y/Q and the wear on the right and left wheel rim of the front axle of wagon 171 with new wheel profile (dashed line) and wagon 172 with hollow wheel profile (solid line). The derailment coefficient is lower with the wheel worn profile when compared to the new wheel profile. The reason is because the lateral force is lower when the track fits into the wheel hollow during curving.

In this paper, the Wear Index is represented by the energy dissipation in wheel-rail contact T_γ , which can be calculated as the product of creepages and creep forces, according to Kalker theory. $T_\gamma = (F_x\mu_x + F_y\mu_y + M_s\mu_s)$ is used to define the wear number. F_x and F_y are the longitudinal and lateral creep forces and M_s is the moment in the torque direction. μ_x , μ_y and μ_s are the longitudinal, lateral and spin creepage [12].

From the 4km position, which is the transition of entry into the curve, the twin couple decelerates. From this point, the left wheel presents peaks in the Y/Q due to the contact between the flange of the wheel profile and the rail. Thus, it can be inferred that lateral force increases at the point of contact, during the transition, but is attenuated in curve.

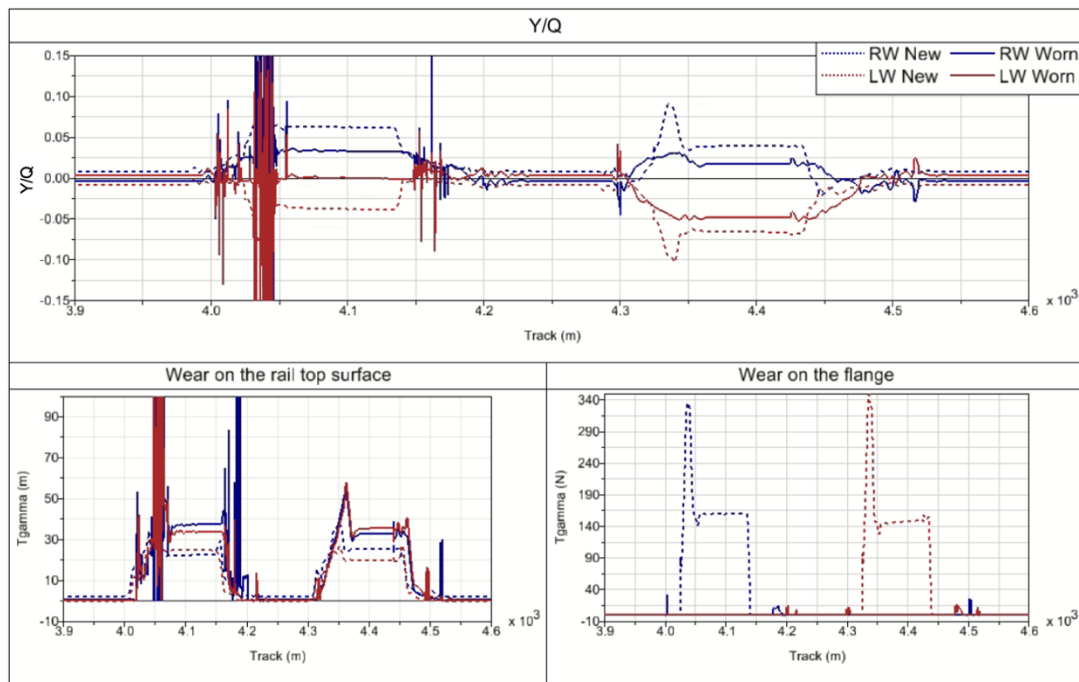


Figure 4: Y/Q and wear on the Wheels.

The comparison of the wear on the flange for the two wheels profiles is shown in Figure 4. From that, the wear is greater for the new wheel profile, because the rail has contact with the flange while the worn wheel hasn't, as the track remains in a fixed position in the worn wheel. For the wheel tread, the wear in the worn wheel is higher than in the new wheel profile. This means that the wear will be intensified in the already hollow area on long tracks.

Figure 5 illustrates the consequence of the hollow wheel in the contact patch. As the wheel fits the hollow in the track profile, the contact ellipse occurs in an outer position for the opposite wheel (yellow) when compared to a new wheel (grey) for a tangent section. Tangential forces are represented in purple and normal forces in black. During curving, the contact patch is concentrated in the flange root, other than tread and flange as happens in a new wheel.

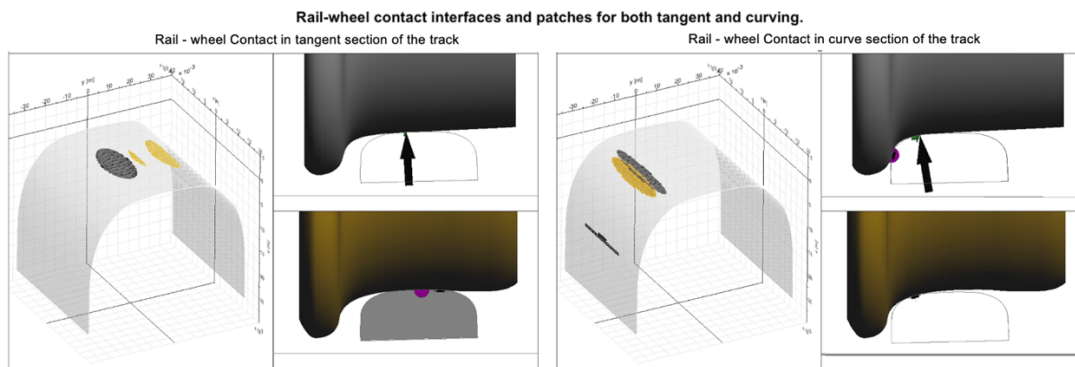


Figure 5: Contact Ellipses.

4 Conclusions and Contributions

A total dynamic model was built in SIMPACK representing a couple of gondola freight rail vehicles. This couple was connected to a convoy using dynamic models of couplers and draft gear devices via the interface MATLAB/Simulink – SIMPACK/MatSIM. A speed profile featuring acceleration notches and dynamic brake was implemented as an input for the vehicles along a track with theoretical irregularities generated by PSD. Such a multibody model can be used to simulate case studies from real situations observed in the railway.

The dynamic effect caused by worn wheels in this twin couple model is studied. It is observed that the derailment safety coefficient Y/Q is lower when compared to new profile wheels. The wear number on wheel tread in the hollow region is higher than for new wheels and it will add up along the course. Due to the hollow profile, the contact point is moved further the center of the rail, avoiding flange contact in curve and consequently decreasing flange wear.

As future works, the even more realistic model of the pair of freight wagons will be evaluated, occupying different positions along the train with misaligned bogies,

uneven braking, different wheel radii, breakage of suspension system and unbalanced load, typical scenarios existent in real railways.

Acknowledgements

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