MULTIBODY MODEL OF A BRAKE RIGGING MECHANISM OF A FREIGHT WAGON

Francesco Mazzeo, Matteo Santelia, Michele Vignati, Egidio Di Gialleonardo and Stefano Melzi

Department of Mechanical Engineering
Politecnico di Milano
Via La Masa, 1 I-20156 Milan, Italy
francesco.mazzeo@polimi.it

EXTENDED ABSTRACT

1 Introduction

This article investigates the dynamic response of a brake rigging mechanism installed on a new-generation articulated freight wagon. A multibody model of the mechanism was developed to analyze its interaction with a wheel-slip-prevention system (WSP). Such a system modulates the brake force to avoid locking the wheels during high-intensity braking and does not equip the examined freight wagon. This work represents a preliminary step for designing and installing a cheap WSP on the vehicle. The main purpose of the study is to analyze possible interferences between the operating frequencies of WSP and the eigenfrequencies of the rigging mechanism. Such interferences might compromise the proper functioning of WSP, affecting the braking performance too [1] . The first part of the work describes the development of a multibody model of the system using the software Simscape, a Matlab/Simulink toolbox. The model includes the effect of non-linearities due to the contact between bodies and clearances. The second part of the work presents the validation of the model against experimental data collected on a real bogie. A comparison between experimental measurements and results of numerical simulations is performed, underlining the pros and limitations of the model. Finally, a dynamic analysis of the system during a braking maneuver is performed to estimate the frequency response function (FRF) between the pressure in the braking cylinder and the contact force between the shoe and the wheel.

2 Multibody model

The vehicle analyzed in this paper is the articulated freight wagon T3000e, as it is one of the most common freight vehicles in Europe. The wagon is composed of 2 frames, 3 bogies and 6 wheelsets. The extremity bogies and the central bogie are equipped with two different types of brake rigging systems. In this work, for sake of brevity, just the dynamics of the rigging mechanism of the middle bogies are studied. Fig.1 shows the multibody model of the rigging mechanism mounted on the central bogie.

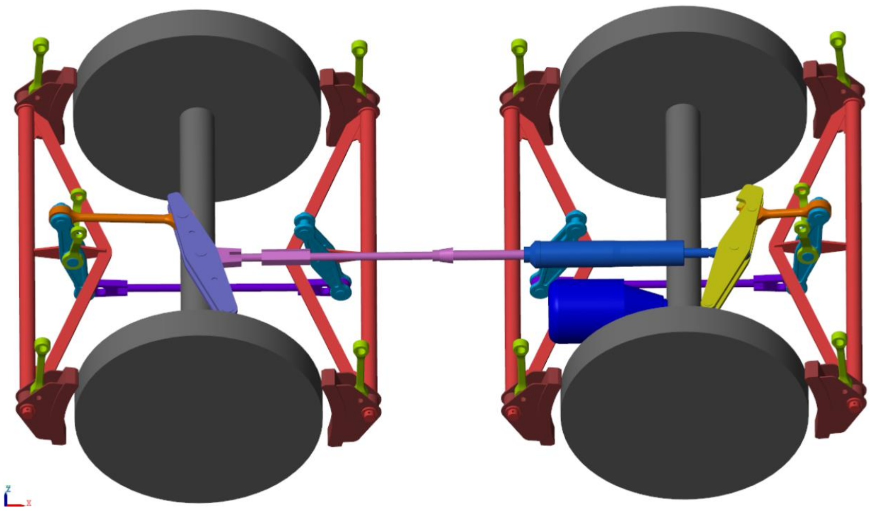

Fig. 1 – Multibody model of the rigging mechanism of the middle bogie

The dynamics of the rigging mechanisms is studied using a multibody model built with Simscape, a dedicated multibody tool of the software Simulink-Matlab^{TM}. The model includes rigid bodies, linear spring-damper elements, actuators, nonlinear joints and constraints. To set up the system properly, each connection between bodies is modelled through ideal connections, considering the absolute and relative degrees of freedom (d.o.f.) of the system. In addition, backlashes relative to some joints are introduced. From the mathematical point of view, backlashes are nonlinear springs, that represent an additional d.o.f. with limitations: when the position of the d.o.f. exceeds a given threshold, called slack range, the stiffness increases. Hence, a repulsion force rises, simulating the contact between different components. Moreover, a nonlinear damper element is added in parallel to the nonlinear spring to account for energy dissipation and mitigate numerical issues. Finally, the contact between the brake blocks and the wheel is introduced: the component of the impact force normal to the wheel is computed according to the Lankarani-Nikravesh model [3].

3 Experimental test and model validation

The multibody model is validated by evaluating the braking performance targets required by the technical specifications of the bogie for what concerns steady-state value. The bogie specifications indicate the normal contact force between the brake blocks and the wheel at a given pressure. These values are compared with the results obtained from the simulations where the design pressure is used as input. Regarding the dynamic response of the system, experimental data are used. The experimental tests consist in the measurement of the displacements of some meaningful points of the system during a free decay test. Then, the same conditions are simulated with the model and the results of the simulations are compared with the acquired data. To perform the measurements, three laser displacement sensors M7L/200 are used. Finally, the agreement of the simulations and the measurements proved the validity of the model.

4 Dynamic Analysis

During the activation of the WSP valve, the pressure inside the cylinder varies with a frequency higher than typical operative conditions [2]. This could lead to a dynamic interaction with the brake rigging eigenfrequencies preventing the WSP to operate properly. The frequency response function (FRF) is computed considering, as input, the pressure inside the cylinder, and, as output, the normal contact force at the shoe-wheel interface. Furthermore, since the system is not linear, the FRF will be computed considering different amplitudes of the input pressure. The system is excited with a sinusoidal pressure acting on the cylinder, as shown in fig. 2. When the pressure is applied, the shoes start to move towards the wheel. In the first part of the cycle, since there is a small clearance between the shoes and the wheel, the normal contact force is null. Then, when the shoes touch the wheel, the normal forces at the contact interfaces start to increase, following the pressure trend. Hence, the spectra of the normal force resulting at the shoe-wheel interface are computed by performing a Fast Fourier Transform (FFT). This procedure is repeated for several input pressures at different frequencies, starting from 0.5 Hz up to 10 Hz. In this way, it is possible to obtain the FRF between the input pressure and the normal contact force between the shoes and the wheel.

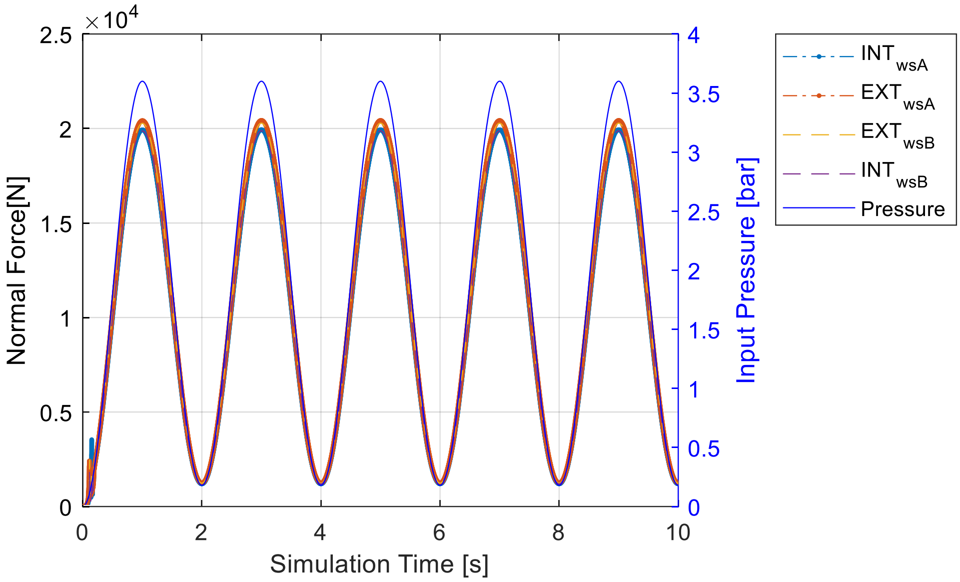

Fig. 2 – Multibody model of the rigging mechanism of the middle bogie

4 Conclusions

In this work, the dynamics of the rigging mechanism of the freight wagon T3000e are analyzed. The aim of the work is to evaluate the dynamic response of this mechanism in order to check its interaction with a Wheel-Slip-Prevention (WSP) system that avoids the complete locking of the wheels during high-intensity braking maneuvers. The main result of the work is the Frequency-Response-Function (FRF) between the braking pressure and the normal contact force at the shoe-wheel interface. Being the system nonlinear, a sensitivity analysis has been performed computing the FRF for different input pressures. In all the considered cases, the results show that the eigenfrequencies of the rigging mechanism are well above those of the WSP system. Consequently, to design a WSP control logic for this type of wagon, the dynamic of the rigging mechanism can be neglected.

References

[1] Wu Q. et al. (2021) Freight train air brake models, International Journal of Rail Transportation. https://doi.org/10.1080/23248378.2021.2006808

[2] Allotta, B. & Conti, Roberto & Meli, Enrico & Pugi, Luca & Ridolfi, Alessandro. (2013). Development of a HIL railway roller rig model for the traction and braking testing activities under degraded adhesion conditions". International Journal of Non-Linear Mechanics. 57. 50-64. 10.1016/j.ijnonlinmec.2013.06.003.

[3] Lankarani, H.M., Nikravesh, P.E. Continuous contact force models for impact analysis in multibody systems. Nonlinear Dyn 5, 193–207 (1994). https://doi.org/10.1007/BF00045676