The Fifth International Conference on Railway Technology
RAILWAYS 2022
22–25 August 2022
Montpellier, France

Proceedings of the Fifth International Conference on
Railway Technology:
Research, Development and Maintenance
Edited by J. Pombo
Civil-Comp Conferences, Volume 1, Paper 4.15
Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.1.4.15

A Virtual Laboratory for Pantograph Modelling Identification and Validation

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Abstract

Rail electrification make use of the interaction between pantograph and Overhead Contact Line (OCL) to provide power to railway vehicles. Advanced computational tools are used to help understanding the restrictions and limitations imposed on the OCL and pantograph systems for reliable operation. The numerical analyses can simplify and decrease the costs of electrification, by reducing the need for expensive on-track testing to ensure compatibility. In this work, a virtual laboratory is developed to validate Multibody (MB) models of pantograph by comparing their frequency response with the experimental results that are gathered in test benches, which are used to obtain the Lumped-Mass (LM) models. As the state-of-the-art solution for pantograph-OCL interaction studies includes the use of MB models, it is important to increase the confidence on these models. The MB methodology frequently requires fine tuning of the modelling parameters to tackle eventual uncertainties associated to the properties of the suspension elements or linking components. The virtual laboratory proposed here enables to do increase the accuracy and validate the MB models by ensuring that the experimental data is accurately represented. The pantograph MB approach allows to overcome the LM limitations, as the parts of the MB model represent the components of the real pantograph, is a fully 3D formulation and allows to consider aerodynamic drag and uplift forces on individual parts.

Keywords: Pantograph-OCL, Current collection performance, Multibody systems

1 Introduction

The operation of an electric railway network depends heavily on the interaction between the pantograph and catenary. The quality and reliability of current collection is one of the limiting factors in raising service train speeds. The development of numerical tools suitable to analyse pantograph-catenary interaction dynamics has been an active field of research over the past years [1]. These tools allow the quantitative study and analysis of this complex interaction, reduce the need for expensive line tests, and support the development of new design solutions through simplified workflows [2].

The virtual pantograph laboratory [3] is a flexible tool designed to represent a range of setups of real-life testing structures using MB methodology. This tool allows for tests previously conducted on pantographs to be replicated in the virtual setup and reproduced on numerical models of the same pantograph. This process speeds up the validation of the numerical models, in which the user can have increased confidence. Fine tuning of the modelling elements is also possible, aiming to improve the accuracy of the results.

In **Figure 1**, a MB pantograph on the virtual laboratory is represented. The pantograph model can be excited at the base or at the head, with vertical and lateral movements. These degrees of freedom correspond to the movements that the pantograph is exposed to during normal operation due to the movement of the carbody and the interaction with the OCL.

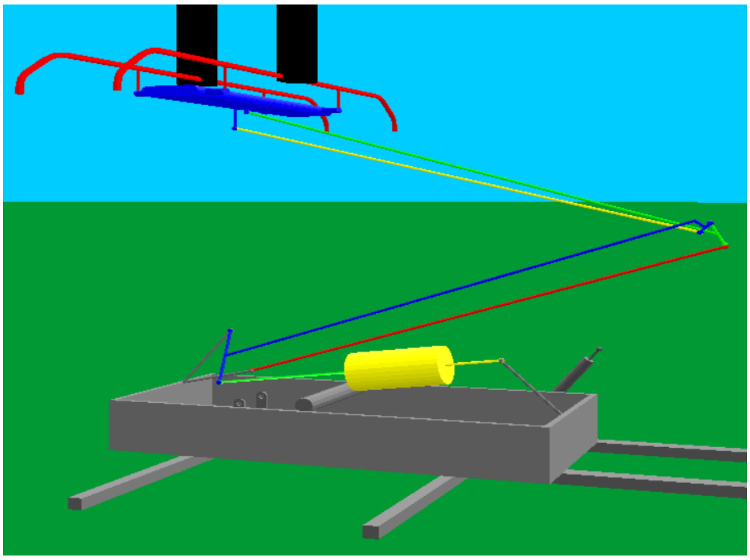


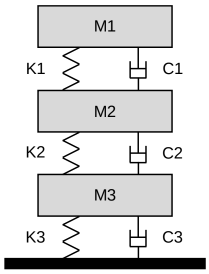
Figure 1: MB pantograph on virtual laboratory.

The main aim of this work is to tune and validate the pantograph numerical models produced using MB methodology, by comparison with the industry standard LM models and experimental data collected in test benches. For this purpose, a MB pantograph is integrated on a virtual environment and validated against experimental data. The accuracy of the numerical models is assessed using a parameter Q available in the standards to confirm the match of the models to validation data.

2. Methods

A MB pantograph model is developed in this work. Then, its medelling properties are tuned using the Virtual Pantograph Laboratory to match experimental results. The pantograph model considered here is composed by 9 bodies, 9 joints, 7 spring-damper elements and 4 bumpstops. The inertial and stiffness properties of each body are taken from material properties and geometry information from the pantograph manufacturer. The fine-tuning exercise helps to identify the best set of parameters for some unknown or hard to measure properties e.g., damping coefficients of links and displacement-force relation for the pneumatic actuator. This is done by matching the dynamic response of the whole system against the dynamic response from the experimental results.

The experimental data considers acceleration, force and displacement responses of the pantograph to the sinusoidal excitations applied at the pantograph head. The measured data is post-processed to produce relevant transfer functions for the identification of the LM model parameters. The transfer functions are expressed as a function of the excitation frequency, also known as Frequency Response Function (FRF), which is used to produce the pantograph LM model. The pantograph LM model considered here is presented in Figure 2.



ID	Value	Units
M1	5.30	kg
M2	7.50	
M3	3.53	
K1	6300	N/m
K2	5000	
K3	0	
C1	70	Ns/m
C2	0	
C3	32.6	

Figure 2: Pantograph LM model, from [4].

The virtual lab is setup using, the MB formulation, to replicate the main parts and joint elements that are used to attach the physical pantograph to the experimental test bench. Then, the pantograph MB model is integrated in the virtual lab and the tests are performed as if in the physical test bench, i.e., the excitation signals are produced to recreate the excitation to the head of the model (vertically and laterally) with the same characteristics as in the experimental campaign.

The FRF of the MB model is calculated from the measurement data at discrete frequency values, corresponding to the excitation frequency of the input signal. The numerical results obtained in the virtual lab are analysed as amplitude and phase differences between the input and the response signals for each frequency of excitation. The main FRF used in this work corresponds to the contact force generated at the interface between the pantograph head and the excitation bar by a unit of vertical displacement of mass with imposed displacement. This type of FRF corresponds to a receptance function, as it relates a force reaction to the excitation displacement.

An accuracy parameter Q, defined in equation (1), is used to evaluate the accuracy of MB model in representing the real pantograph. This indicator compares the FRF of numerical and experimental results as defined in the standards [5,6]. The equation available in EN 50318:2018, is extended here to compare the receptance of the MB model, defined as:

$$Q = \left(1 - \frac{1}{f_n - f_1}\left(\sum_{i=1}^{n-1}(f_{i+1} - f_i)\left|1 - \frac{log|X, model, i|}{log|X, measured, i|}\right|\right)\right) \times 100\% \quad (1)$$

where *X* corresponds to the quantity in comparison, i.e., receptance. *model* values relate to quantities obtained from the numerical model, while *measured* values relate to experimental data. *f* corresponds to the discrete frequency values.

3 Results

The LM and MB pantograph models are analysed in the test setup defined for the identification of the LM model in laboratory. On this test, the frequency is swept between 0.2 Hz and 20 Hz in logarithmic steps. This frequency range represents a small extension in relation to the range defined in EN50318:2018 [5] for similar analysis of numerical models, i.e. [0.5, 20] Hz, to better represent the low frequency range information available in the experimental data. The amplitude varies with the frequency in an inverse function, i.e., higher frequency, lower amplitude; with values ranging between 40 and 0.95 mm. The receptance (frequency response function between contact force and contact point displacement) of MB and LM models is presented in **Figure 3** as a function of the excitation frequency. The values can be compared against the experimental results obtained in the test bench.

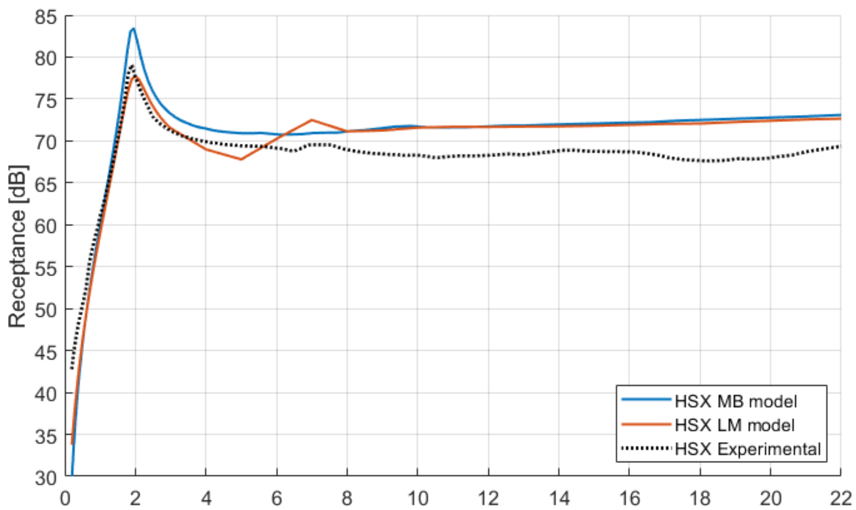


Figure 3: Receptance (FRF) of LM and MB models with experimental results.

The comparison of LM and MB models is also done using the Q indication of model accuracy. In **Table 1**, the Q values for the MB and LM models is available for the comparison against the experimental results. The very high Q values, over 98.5% indicate the good match between the numerical models and the experimental results. The results present some divergence at the low frequency range (<1 Hz) and some excessive gain for exciting frequencies over 8 Hz. The main resonant frequency and general behaviour of the function is very satisfactory, as indicated by the high Q value.

	Q5 [%]	Q20 [%]
EN50318 (Required)	>90	>90
Lumped Mass HSX	99.3	99.0
Multibody HSX	98.9	98.9

Table 1: Accuracy parameter (Q) of LM and MB pantograph models.

4 Conclusions and Contributions

This work presents a virtual laboratory to study and compare the dynamic performance of LM and MB models of pantographs. The results demonstrate that the tool can be used to fine tune the modelling parameters of the MB model to better replicate the experimental results obtained with the real pantograph. The analysis covers parameters that are of difficult identification, such as, damping coefficients or displacement-force non-linear relations of pneumatic actuators. Furthermore, the virtual lab demonstrates its flexibility to model different actuators configuration, test setups and excitation profiles.

Future developments of this work include the automation of the processes for identification of LM pantograph models, with linear or non-linear linkages, e.g. non-linear stiffness or damping characteristics that change to better replicate the working height of the pantograph. The improvement of the modelling of complex structures on the MB models, such as the CAM elements on the pantograph elbow or the pneumatic actuator at the base can improve the accuracy of the numerical model in respect to the experimental results. The use of the flexible bodies to represent some pantograph parts is also of interest for future developments.

Acknowledgements

This work was supported by the railway industry and funded by RSSB (project COF-UOH-49). This work was supported by FCT, through IDMEC, under LAETA, project UIDB/50022/2020.

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