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 4.2
Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.1.4.2

A Pantograph-Catenary Dynamic Analysis Tool to Support Railway Electrification Projects

P. Antunes[12], J. Pombo[123], J. Ambrósio[2], J.M. Rebelo[1], J. Santos[1]

[1] Institute of Railway Research, School of Computing and Engineering, University of Huddersfield, United Kingdom.
[2] IDMEC, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal.
[3] ISEL, Instituto Politécnico de Lisboa, Lisboa, Portugal.

Abstract

The race for lower carbon emissions pressures railway transportation to meet demanding electrification goals. Infrastructure managers seek ways to electrify their network at an accelerated pace, challenging the industry for a faster, cheaper and less disruptive electrification. This includes the electrification of their current networks, as well as upgrading parts of older infrastructure to cope with increased traffic and operating speeds, while still planning network expansion. Conversely, rolling stock manufacturers carry the heft on providing an interoperable train-pantograph configuration able to perform through different parts of the network with different catenary designs. In this fast paced and complex environment, set to meet strict electrification goals, the industry seeks the employment of pantograph-catenary interaction dynamic analysis tools to validate and verify their design solutions at an accelerated pace, as well as provide a degree of assurance to the network. The employment of numerical analysis tools to analyse the pantograph-catenary interaction dynamics has a crucial role to better understand and improve its performance. Additionally, these tools aid the development of new technologies and de-risk their introduction into service, while substantially reducing the need of expensive line tests. However, the capability of these numerical tools has been limited to pantograph-catenary dynamic analysis set in single straight railway tracks. The industry seeks these tools to aid, accelerate and validate in locus electrification projects which require the consideration of the track geometry and other aspects such as catenary systems set in multiple tracks. In this work, a new modelling and dynamic analysis framework is developed to respond to the industry demands in being able to employ these tools in a project design environment. The use of the framework enables catenary systems to be automatically modelled following the track geometry and catenary layout provided as input. It also enables the consideration of catenary systems set in in any general track geometry, such as curves, as well as being composed of more than one track.

Keywords: Railway Systems, Pantograph-Catenary Dynamics, Overhead Contact Line, Advanced Numerical Tools, Electrification.

1 Introduction

Railway transportation plays a key role in worldwide transportation. As globalization and economic growth significantly increase the demand for passenger and freight mobility. Moreover, the present demand for sustainable and green transportation puts in a challenge for railway transport decarbonization. This has resulted in a vast worldwide program to remove from service diesel fleets and replace them by trains running on alternative power sources, in which rail electrification plays the main role.

Although railway electrification is a sustainable solution, it requires a significative starting capital investment. Thus, the railway industry is challenged in being able to carry a cost-effective, accelerated electrification. The railway sector is also enquired to have versatile and interoperable rolling stock, capable to run in different networks. This raises difficulties in the authorization processes, required to ensure compliance with performance and safety standards. Here, the need to reduce or avoid expensive in line tests is also a key aspect challenged by the railway industry, which finds difficulty on introducing new technologies.

Recent developments on computational tools, able to study with detail the pantograph-catenary dynamics, have been employed to better understand the interaction between these two systems [1]. Some of these tools have also been able to reduce inline tests, such as in the case of European technical specifications for interoperability. The industry is more receptive to perform the homologation procedures based on numerical simulations rather than on in-line measurements, which are very expensive and time consuming. However, it also has raised more challenges on the ability of this tools to be able to study and handle more complex problems.

Pantograph–catenary interaction tools currently in use share part of the modelling approaches and some of them have been successfully validated. A more restricted number of them have also been certified following EN50318:2018 [2]. Nevertheless, presently most numerical tools available are limited to catenary models set in straight track and studied in interaction with lumped mass pantograph models.

The study of more complex problems requires advancements in the capabilities of these software, such as the ones implemented in *PantoCat* [3]. In this work, the most recent advancements of this computational tool are presented, addressing critical aspects to be accounted when considering the analysis of complex current collection systems. This includes the development of a dynamic analysis framework which enables the industry to be able to employ these tools in a project design environment.

2 Methods

PantoCat is a computational tool able to analyse pantograph–catenary dynamic interaction in realistic operating conditions. The catenary and pantograph sub-models address complete overhead energy collecting systems that include all mechanical details of the pantograph components and the complete topology and structural details of the catenary [3]–[5].

In general, the development of pantograph-catenary dynamic analysis tool is a multidisciplinary exercise. *PantoCat* uses the Finite Element (FE) methodology [6] to study the catenary and the multibody formulation [7] to represent the pantograph [8]. These two heterogenous formulations are integrated via an efficient co-simulation environment [9]. Both sub-modes are bridged through a contact model based on a penalty formulation. Presently, *PantoCat* is extensively used in research and consultancy projects for the rail industry, being certified by an independent notified body to EN50318:2018 standard [2]. It is a fully three-dimensional (3D) tool, capable of modelling rigid and flexible catenaries with multiple sections, including overlaps [10] and gradients. Multiple pantograph operation can be considered [11], as well as other complex loads on the components, including aerodynamic effects [12], [13]. A geometric reconstruction algorithm, [14], enables a geometry pre-processor to be able to spatially define the position of all the catenary model finite element nodes and elements according to track data, such as curvature, cant and elevation. To this effect, the geometry pre-processor establishes a moving frame of reference as a function of the track travel length [15]. As catenary design layouts are set according to the track length and its geometric parameters are set in reference to the track surface, it is possible establish a spatial position for any key point of the catenary design. Hence, dynamic studies in tangent or curved tracks, [16], can be considered as well as additional irregularities and perturbations [17].

The pantograph can be modelled either as staged spring-damper lumped mass system or as a 3D multibody model. The former is a linear representation of the pantograph, where model parameters are identified experimentally to match the same frequency response of the pantograph. Although these models reproduce with fidelity the dynamic response of the real pantograph, the identified parameters have no physical realism and the model validity is limited to the test setup parameters such as working height. The multibody model approach is also implemented in *PantoCat* with the aim to provide a better physical representation of the pantograph, including its nonlinear behaviour.

3 Results

The dynamic analysis tool here presented follows an integrated framework environment, established between different modules as depicted in Figure 1. A track geometry processing tool is able to build a moving frame of reference of a track through geometric reconstruction, using track geometry parameters such as the curvature, cant. Hence, the position and spatial orientation of the track can be obtained at any length and fed to the following modules.

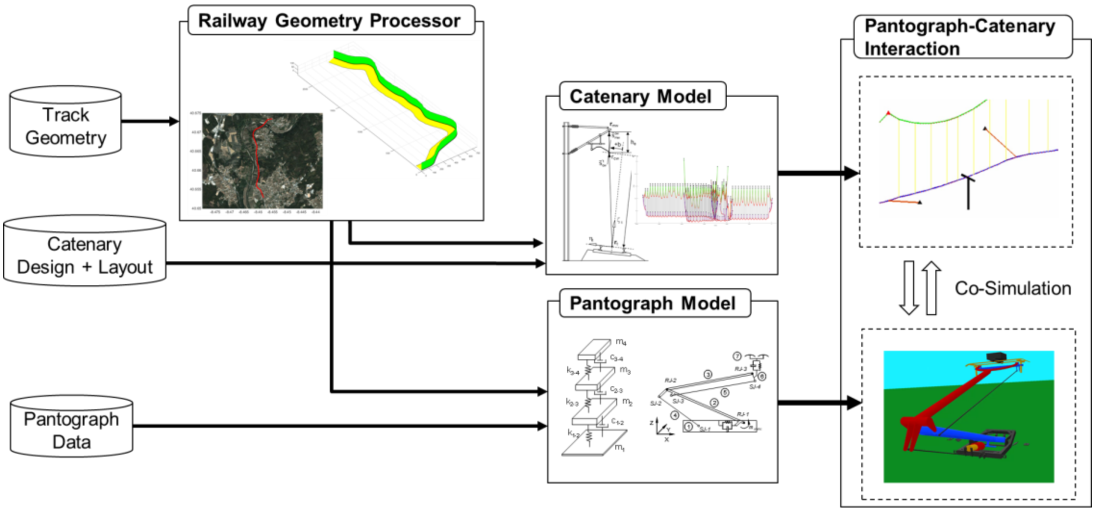

Figure 1: Dynamic analysis tool framework.

Several track geometries can be stacked in cases where the catenary system is set in multiple tracks. The catenary module is able to build a catenary finite element model of the hole overhead line system to be considered, according to additional catenary design data which is also parametrized along the track length. The pantograph module is also able to employ the railway geometry database to set the spatial path of the pantograph along the track, or in other cases a secondary database can be provided to include vehicle movements and oscillations. A co-simulation module couples the dynamic effects between the generated catenary and pantograph models, to analyze its interaction in the time domain. Note that this framework scheme effectively separates the analysis tool into several modules. These modules can be used independently when particular types of analyses are necessary. It also enables each of the sub-systems to be numerically modelled with a mathematical formulation that is best suited for each case. *PantoCat* modular architecture has the advantage of allowing each module to run independently, providing a unique development platform where both modules can be developed individually, its capabilities extended and used for different types of analysis.

The advanced features here detailed allow for the simulation of sophisticated and detailed models of the pantograph and catenary models containing large sets of data. The set of output data includes not only the pantograph-catenary contact forces but also all the kinematics of each mechanical element of the pantograph and catenary, and the internal forces on both systems. These advancements are portrayed in Figure 2, which presents the finite element model of a comprehensive catenary system installation regarding a junction of four railway tracks merging into two. The model considers the position of all components according to the track geometry and catenary layout designs provided. It also accounts for gradients and an under bridge.

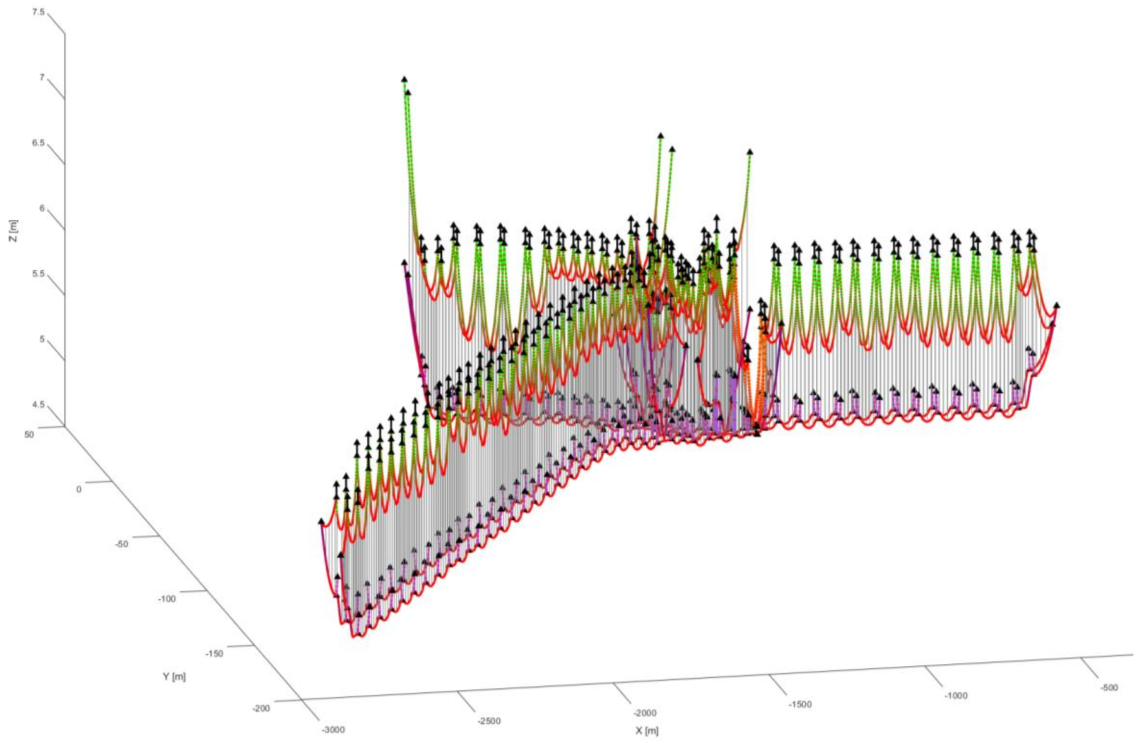

Figure 2: Model of a catenary system set at a railway junction.

4 Conclusions and Contributions

The outcome of the work here detailed presents the development of a robust pantograph-catenary dynamic analysis tool able tackle more complex features. An additional set of modelling methodologies and the development of an integrated framework enables a pantograph-catenary analysis tool, *PantoCa*t, to extend its capabilities and be able to handle more complex problems in response to the most recent industry challenges on electrification. Overhead line infrastructure managers or designers and rolling stock manufactures are able to employ this tool to validate, plan and analyse their technical solutions. This promotes a more efficient and effective electrification at a lower cost, where design solutions can be analysed and de-risked in an accelerated design environment. In general, most dynamic analysis tools are limited to catenary models set in a single straight track. The developed framework aims to enhance an already developed tool to be capable of dealing with catenary models set in arbitrary track geometries and in multiple lines. It also enables the tool to account for more critically realistic cases such as line junctions, cross-overs, gradients and overbridges, among others. In addition to the more common lumped mass pantographs models that retain a strict set of modelling considerations and model validity, this tool also is able to consider novel multibody pantograph models. The set of additional capabilities provided by these developments aim to support the railway industry in adding capability to tackle the demand for accelerated and cost-efficient electrification.

Acknowledgements

The authors gratefully acknowledge the support of the Portuguese Foundation of Science and Technology (Fundação para a Ciência e a Tecnologia) through IDMEC, under LAETA, project UIDB/50022/2020.

References

[1] S. Bruni *et al.*, “The results of the pantograph–catenary interaction benchmark,” *Veh. Syst. Dyn.*, vol. 53, no. 3, pp. 412–435, Mar. 2015.

[2] “EN 50318:2018 - Railway applications - Current collection systems - Validation of simulation of the dynamic interaction between pantograph and overhead contact line.” CENLEC, 2018.

[3] J. Ambrósio, J. Pombo, P. Antunes, and M. Pereira, “PantoCat statement of method,” *Veh. Syst. Dyn.*, vol. 53, no. 3, pp. 314–328, Mar. 2015.

[4] J. Ambrósio, J. Pombo, M. Pereira, P. Antunes, and A. Mósca, “Recent developments in pantograph-catenary interaction modelling and analysis,” *Int. J. Railw. Technol.*, vol. 1, no. 1, pp. 249–278, 2012.

[5] P. Antunes, A. Mósca, J. Ambrósio, J. Pombo, and M. Pereira, “Development of a Computational Tool for the Dynamic Analysis of the Pantograph-Catenary Interaction for High-Speed Trains,” in *Civil-Comp Proceedings*, 2012, vol. 99, pp. 1–25.

[6] K.-J. Bathe, *Finite Element Procedures*, 2nd ed. K.J. Bathe, Watertown, MA, 2014.

[7] P. E. Nikravesh, *Computer-Aided Analysis of Mechanical Systems*. Englewood Cliffs, New Jersey: Prentice-Hall, 1988.

[8] J. Pombo and J. Ambrósio, “Influence of pantograph suspension characteristics on the contact quality with the catenary for high speed trains,” *Comput. Struct.*, vol. 110–111, pp. 32–42, Nov. 2012.

[9] P. Antunes, J. Ambrósio, J. Pombo, and A. Facchinetti, “A new methodology to study the pantograph – catenary dynamics in curved railway tracks,” *Veh. Syst. Dyn.*, vol. 3114, 2019.

[10] P. Antunes, J. Ambrósio, J. Pombo, and M. Pereira, “Dynamic Analysis of the Pantograph-Catenary Interaction on Overlap Sections for High-Speed Railway Operations,” in *Proceedings of the Second International Conference on Railway Technology: Research, Development and Maintenance*, 2014.

[11] J. Pombo and P. Antunes, “A Comparative Study Between Two Pantographs In Multiple Pantograph High-Speed Operations,” *Internatinal J. Railw. Technol.*, vol. 2, no. 1, pp. 83–108, 2013.

[12] J. Pombo and J. Ambrósio, “Environmental and track perturbations on multiple pantograph interaction with catenaries in high-speed trains,” *Comput. Struct.*, vol. 124, no. October, pp. 88–101, Aug. 2013.

[13] J. Pombo, J. Ambrósio, M. Pereira, F. Rauter, A. Collina, and A. Facchinetti, “Influence of the aerodynamic forces on the pantograph–catenary system for high-speed trains,” *Veh. Syst. Dyn.*, vol. 47, no. 11, pp. 1327–1347, Nov. 2009.

[14] W. C. Iverson, “Analysis of the Reconstruction of Rail Geometry from Curvature Data,” *IEEE Trans. Ind. Appl.*, vol. IA-10, no. No. 3, pp. 368–379, May 1974.

[15] J. Ambrósio, P. Antunes, and J. Pombo, “On the Requirements of Interpolating Polynomials for Path Motion Constraints,” in *Mechanisms and Machine Science*, vol. 26, A. Kecskeméthy and F. Geu Flores, Eds. Springer International Publishing, 2015, pp. 179–197.

[16] P. Antunes, J. Ambrósio, J. Pombo, and A. Facchinetti, “A new methodology to study the pantograph–catenary dynamics in curved railway tracks,” *Veh. Syst. Dyn.*, vol. 58, no. 3, pp. 425–452, Mar. 2020.

[17] Y. Song, P. Antunes, J. Pombo, and Z. Liu, “A methodology to study high-speed pantograph-catenary interaction with realistic contact wire irregularities,” *Mech. Mach. Theory*, vol. 152, p. 103940, Oct. 2020.

[18] J. Ambrósio, J. Pombo, F. Rauter, and M. Pereira, “A Memory Based Communication in the Co-Simulation of Multibody and Finite Element Codes for Pantograph-Catenary Interaction Simulation,” in *Multibody Dynamics*, no. 3, E. Bottasso C.L., Ed. Dordrecht, The Netherlands: Springer, 2008, pp. 211–231.