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 4.5
Civil-Comp Press, Edinburgh, United Kingdom, 2022, doi: 10.4203/ccc.1.4.5

Improvements of the pantograph-catenary interaction: numerical simulations and experimental tests on the Italian high-speed overhead contact line

D. Anastasio[1], S. Marchesiello[1], L. Garibaldi[1], C. Spalvieri[2], A. Iacomelli[2]

[1]Dipartimento di Ingegneria Meccanica ed Aerospaziale, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129, Torino.
[2]Rete Ferroviaria Italiana, Piazza della Croce Rossa 1, 00161 Roma.

Abstract

The problem of accurately simulating the pantograph-catenary interaction is of crucial importance in the design and understanding processes of the overhead contact line (OCL) dynamics. In particular, OCLs are known to be very low-damped structures, with a high modal density in the low-frequency region. This has a significant impact on the interaction with the pantograph, especially in the high-speed case. Therefore, being able to optimize the damping distribution of such structures might be an efficient way of improving the current collection quality of existing lines. This theoretically means gaining a smoother contact between the OCL and the pantograph(s), as well as the possibility to increase the train speed above the present limits, still in compliance with the current operational rules. This is a particular issue in the case of two running pantographs, where the rear one (trailing) usually behave worse than the front one (leading).
In this work, a new tool for simulating the pantograph-catenary interaction is introduced, called Cateway. The software is first validated according to the standard EN50318, and then adopted to evaluate the effects of localized alterations in the damping distribution using improved damping droppers. Experimental functional tests are also conducted on a real overhead contact of RFI line to identify its damping distribution and to test the capability of the abovementioned devices to increase its damping properties in the frequency region of interest.
The results of these tests give useful insights about the dynamics of the OCL structure, and on the enhanced damping capability of the tested device. Eventually, Cateway is adopted to replicate the experimental outcomes, and to simulate the effects of the

improved damping droppers on the contact force. Results show remarkable improvements of the current collection quality, especially for the trailing pantograph in the case of two running pantographs.

Keywords: pantograph catenary interaction, overhead contact line, contact dynamics, vibration analysis.

1 Introduction

The problem of accurately simulating the pantograph-catenary interaction is of crucial importance in the design and understanding processes of the overhead contact line (OCL) dynamics [1]. This task is particularly challenging for multiple reasons, and previous studies have shown that particular importance should be given to the choice of the numerical integrator parameters, so as to correctly reproduce the wave propagation phenomena that characterize the dynamic response of the structure [2,3]. Furthermore, OCLs are known to be very low-damped structures, with a high modal density in the low-frequency region [4,5]. This has a significant impact on the interaction with the pantograph, as well as on the fatigue stress that is exerted on the OCL [3,6,7]. Therefore, being able to optimize the damping distribution of such structures might be an efficient way of improving the current collection quality of existing lines. This theoretically means gaining a smoother contact between the OCL and the pantograph(s), as well as the possibility to increase the train speed above the present limits, still in compliance with the current operational rules (for instance the TSI in Europe [8]). This is a particular issue in the case of two running pantographs, where the rear one (trailing) usually behave worse than the front one (leading).

In this work, a new tool for simulating the pantograph-catenary interaction is introduced, called Cateway. The software has been developed at Politecnico di Torino by the Dynamics and Identification Research Group, and it is adopted in this work to evaluate the effects of localized alterations in the damping distribution using improved damping droppers. Experimental functional tests are also conducted on a real overhead contact of Rete Ferroviaria Italiana (RFI) line to identify its damping distribution and to test the capability of the abovementioned devices to increase its damping properties in the frequency region of interest.

The results of these tests give useful insights about the dynamics of the OCL structure, also in the presence of damping droppers. Cateway is eventually adopted to simulate the effects of the damping droppers on the contact force, by computing the dynamical interaction between the OCL and two running pantographs. Results show notable improvements of the current collection quality, especially for the trailing (rear) pantograph.

2 Methods

Cateway is used in this work to simulate the pantograph-catenary dynamic interaction. The software is based on Matlab® programming language and it can be used to:

- simulate the pantograph-catenary interaction of AC and DC lines with multiple pantographs;
- simulate concentrated load tests, such impulse responses;
- perform the modal analysis of the OCL and the pantograph;
- evaluate the effects of variations in the simulation parameters, such as the tension of the wires;
- evaluate the effects of external disturbances or degradations of the contact wire;
- design new improvements for existing OCLs.

The main characteristics of the software are also listed in the following:

- 2D or 3D FE formulation for contact, messenger and potential auxiliary wires, based on the Euler-Bernoulli beam theory;
- droppers modelled as nonlinear springs to take into account the slackening phenomenon [2];
- steady arms modelled as lumped systems with equivalent bending and axial stiffnesses;
- pantograph modelled as a three-degree-of-freedom system with a penalty contact model;
- Iterative Generalized-α [9] numerical integration schemes, as recommended in [3].

Furthermore, it has the possibility of importing OCL geometries as Excel files and it is built with a user-friendly graphical interface (Figure 1).

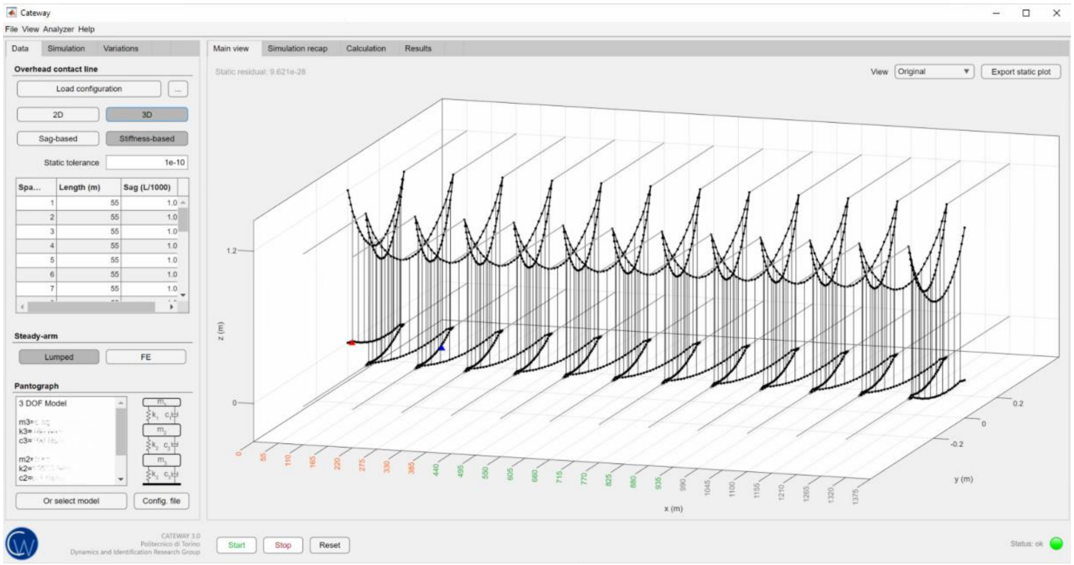

Figure 1: Graphical interface of Cateway.

Damping is added in Cateway using a proportional distribution, whose values are generally determined empirically. In the considered experimental case of the RFI line, free-decay tests have been performed between Milan and Bologna to extract natural frequencies and damping ratios using the Stochastic Subspace Identification (SSI) technique [10]. A scheme of the experimental setup is depicted in Figure 2. Three mono-axial accelerometers (A_1, A_2, A_3) are positioned in different points of the contact wire, and a camera is also used to record the displacement S_2 of the point 2.

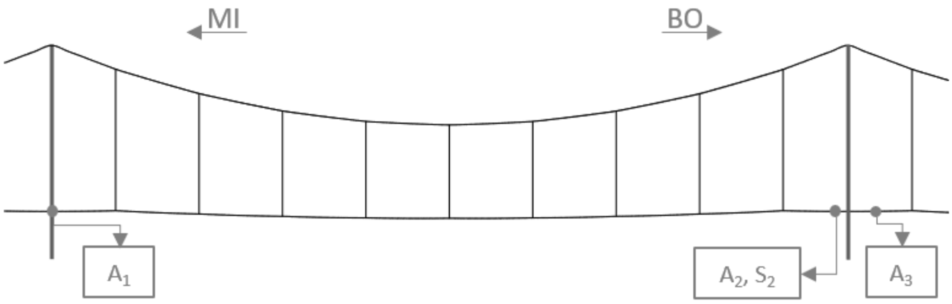

Figure 2: Instrumentation of the RFI line.

The contact wire is lifted of 6 cm in correspondence of point 2 and let it free to oscillate to measure the free response, with a sampling frequency of 512 Hz for 120 s. As for the camera, digital image correlation is adopted to extract the displacement from the recorded video at 120 fps, as depicted in Figure 3. The results of the functional tests are presented in the following section.

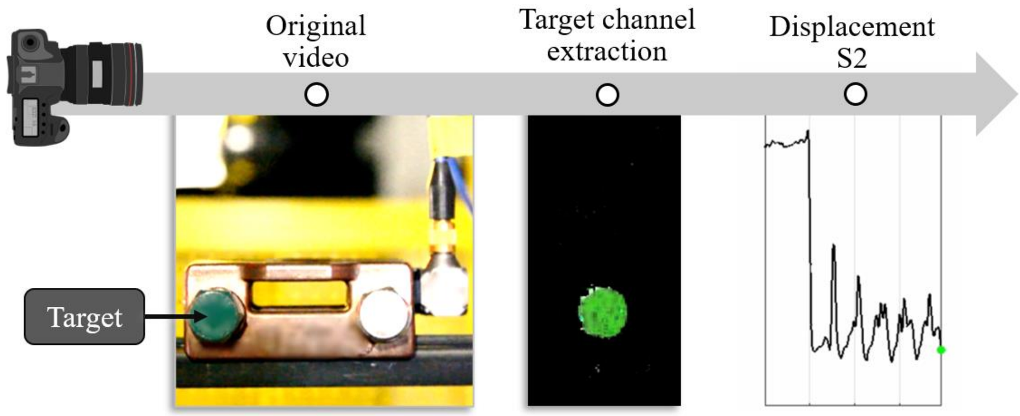

Figure 3: Extraction of the displacement from the recorded video.

3 Results

The first results concern the validation of Cateway with respect to the EN standard [11]. The main target of the validation is related to the contact force, whose statistical parameters must lay inside given ranges for both leading and trailing pantographs. The results are listed in Table 1 for the AC simple line.

Parameter	AC, 320 km/h		AC, 275 km/h	
	Reference	Cateway	Reference	Cateway
Mean value (N)	[166.5-171.5]	[170.1] [169.1]	[141.5-146.5]	[142.5] [142.1]
Standard deviation 0-20 Hz (N)	[49.5-62.9] [30.2-43.8]	[50.6] [37.6]	[31.9-34.8] [50.0-54.5]	[33.5] [54.2]
Standard deviation 0-5 Hz (N)	[38.7-44.4] [14.3-23.3]	[40.2] [14.6]	[26.4-28.9] [41.2-45.4]	[26.7] [45.3]
Standard deviation 5-20 Hz (N)	[29.0-46.2] [26.7-38.2]	[30.7] [34.6]	[16.2-22.4] [25.2-34.7]	[20.2] [29.7]
Maximum value (N)	[295-343] [252-317]	[297] [282]	[219-244] [241-290]	[239] [289]
Minimum value (N)	[55-82] [21-86]	[67] [66]	[71-86] [14-50]	[78] [32]
Range of displacement (mm)	[39-51] [18-35]	[50] [26]	[38-49] [53-70]	[43] [58]
Maximum uplift (mm)	[57-64] [50-61]	[63] [57]	[37-48] [45-54]	[42] [45]
Loss of contact (%)	[0] [0]	[0] [0]	[0] [0]	[0] [0]

Table 1: Validation of Cateway with respect to the existing standard EN50318:2018 (AC Simple).

As for the experimental tests, the first 30 seconds of the displacement S_2 are depicted in Figure 4 in two cases: the standard OCL and the case with the damping device. It can be seen how the decay time is dramatically reduced when the device is installed, attenuating the low-frequency modes of the structure.

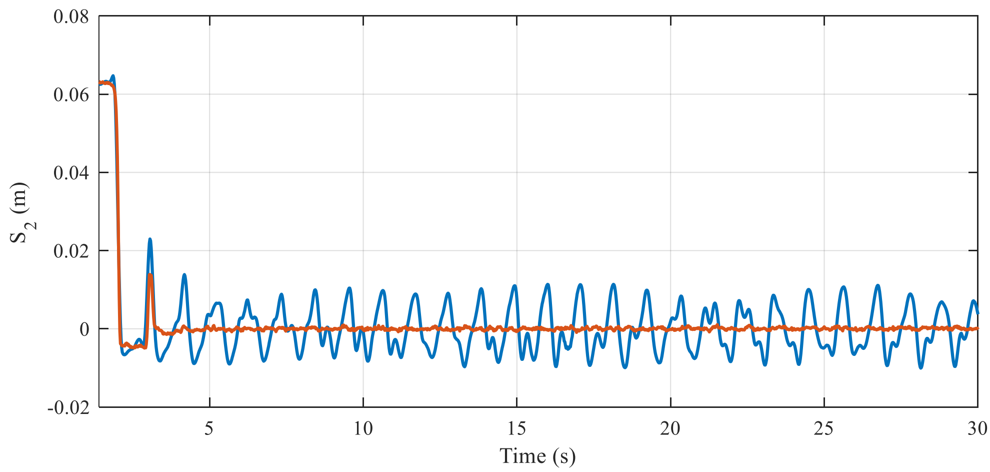

Figure 4: Displacement S_2. Blue line: standard OCL; orange line: OCL+device.

The modal parameters of the structure are identified using the SSI technique. The stabilization diagram is depicted in Figure 5, illustrating the high modal density of the OCL structure.

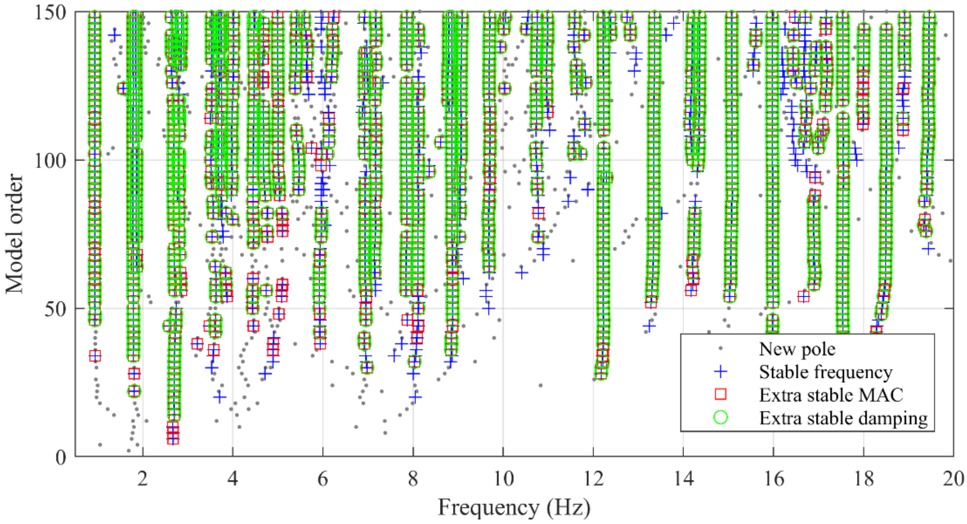

Figure 5: Stabilization diagram, standard OCL. Tolerances of 0.5% on frequency, 10% on damping and 1% on MAC.

The identified natural frequencies and damping ratios are shown in Figure 6, together with the proportional damping fitting. As already highlighted, the effect of the added device is evident in the low-frequency region, especially around the first mode.

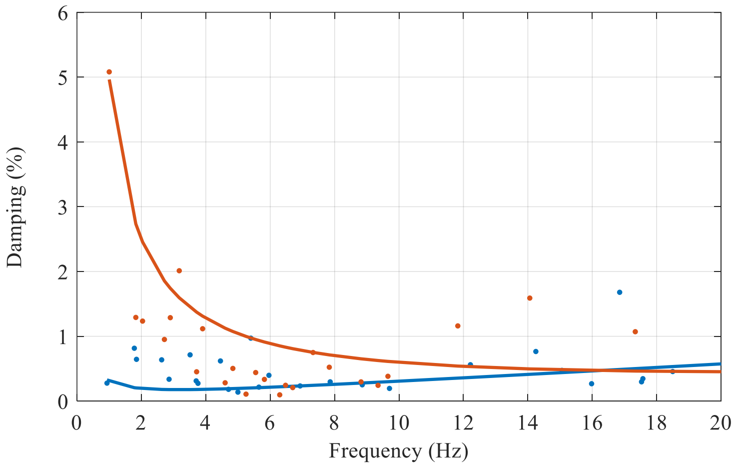

Figure 6: Natural frequencies and damping ratios. Blue dots: standard OCL; blue line: standard OCL, proportional fitting; orange dots: OCL+device; orange line: OCL+device, proportional fitting.

The identified damping model is introduced into Cateway with a model of the RFI line. The effectiveness of the tested devices is simulated considering a double pantograph configuration running at 300 km/h, and comparing the quality of the current collection with and without the devices.

The results are listed in Table 2, where a significant reduction of the standard deviations induced by the improved droppers can be noticed.

Parameter	**Variations, Δ**	**Comment**
Mean value	Leading: ↑ 1 % Trailing: ↑ 1 %	No significant change in the mean values
Standard deviation 0-20 Hz	Leading: ↓ 5 % Trailing: ↓ 30 %	Reduced standard deviations
Maximum value	Leading: ↓ 5 % Trailing: ↓ 25 %	Lower maximum values
Minimum value	Leading: ↑ 20 % Trailing: ↑ >100 %	Higher minimum values
Maximum uplift of the CW	↓ 35 %	Reduced uplift

Table 2: Percentage variations of leading and trailing contact forces simulated by Cateway.

4 Conclusions and Contributions

A new tool for simulating the pantograph-catenary interaction has been introduced in this work. The software, called Cateway, has been adopted to simulate the behaviour of a real overhead contact line of RFI. In order to simulate a reliable dynamic response, experimental functional tests have been performed on the same line to identify a proper damping model. Also, improved damping droppers have been tested to evaluate the induced damping on the line. The effectiveness of these devices has been eventually simulated with Cateway, which confirmed the improvements of the current collection quality, especially for the trailing pantograph in the case of two running pantographs.

Acknowledgements

The authors would like to acknowledge Rete Ferroviaria Italiana for providing the data and supporting the measurements on the line, and Bertolotti S.p.A. for the continuous support of the research activity on the pantograph-catenary dynamic interaction.

References

[1] S. Bruni et al., The results of the pantograph-catenary interaction benchmark, Veh. Syst. Dyn. 53 (2015) 412–435.

[2] Y.H. Cho, Numerical simulation of the dynamic responses of railway overhead contact lines to a moving pantograph, considering a nonlinear dropper, J. Sound Vib. 315 (2008) 433–454.

[3] S. Sorrentino et al., Distributed parameter and finite element models for wave propagation in railway contact lines, J. Sound Vib. 410 (2017) 1–18.

[4] D. Anastasio et al., Analytical investigation of railway overhead contact wire dynamics and comparison with experimental results, Mech. Syst. Signal Process. 116 (2019) 277–292.

[5] P. Nåvik et al., Identification of system damping in railway catenary wire systems from full-scale measurements, Eng. Struct. 113 (2016) 71–78.
[6] J.P. Massat et al., Fatigue analysis of catenary contact wires for high speed trains, 9th World Congr. Railw.
[7] O. Vo Van et al., Waves, modes and properties with a major impact on dynamic pantograph-catenary interaction, J. Sound Vib. 402 (2017) 51–69.
[8] European Commission, On the technical specification for interoperability relating to the infrastructure subsystem of the rail system in the EU, 2014.
[9] J. Chung et al., A Time Integration Algorithm for Structural Dynamics With Improved Numerical Dissipation: The Generalized-α Method, J. Appl. Mech. 60 (1993) 371–375.
[10] P. Van Overschee et al., Subspace Identification for Linear Systems, Springer US.
[11] EN50318: Railway applications - Current collection systems - Validation of simulation of the dynamic interaction between pantograph and overhead contact line (2018).