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Pantograph-Catenary Dynamic Studies on Contact Wire Gradients Considering Aerodynamic Effects

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Abstract

On electrified railways the traction vehicles are powered via the pantograph-catenary interface. Electrification of legacy lines can prove a challenging aspect at level crossings, where the contact wire must manage height variations (gradients), while ensuring suitable current collection. Improvements on pantograph and overhead line equipment design can lead to a reduction on the impact these discrete features have on current collection performance, leading to higher operating speeds, cost savings and reduction in dewirement risk. Advanced computational tools can be used to model realistic overhead systems, and perform dynamic analyses of the pantograph-catenary interaction at critical areas. This enables a substantial reduction in the need for expensive line tests for verification or validation purposes. The main aim of this work is to assess pantograph-catenary dynamic performance at level crossings and overbridges, thus involving contact wire gradients, analysing different pantograph modelling approaches. The results demonstrate that both lumped-mass and multibody pantograph models are virtually non-sensitive to the contact wire height variations, presenting almost a constant contact force profile. However, the state-of-the-art multibody formulation that model the pantograph components with detail, can accommodate the non-linear characteristics of the real system, and include realistic external forces on each body, e.g., aerodynamic loads according to the pantograph opening range. These aerodynamic forces are particularly important when studying catenary gradients, as the pantograph experiences more drag and uplift forces as more extended it is. The developments presented here aid to reduce costs and de-risk rail electrification projects by enabling to understand the current collection performance at different train speeds and gradient steepness.

Keywords: Current collection performance, Level crossings, Overbridges, Rail electrification.

1 Introduction

The design and operation of electric railway systems depends heavily on the interaction between the pantograph and catenary. The quality and stability 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 interaction, reduce the need for expensive line tests, and support the development of new design solutions.

PantoCat [2–4] is one of such tools and the one employed in this work. *PantoCat* is validated against field data in several countries and also certified to EN50318:2018 [5] by a Notified Body (Network Certification Body, UK) for all catenary types. It is able to consider complex modelling features such as 3D catenary systems set in curved tracks [6] and the use of multibody pantograph models [7–10], via an efficient co-simulation procedure [11–13] to integrate the finite element and multibody formulations. *PantoCat* enables to model discrete features of the catenary such as overlaps [14], gradients and irregularities [15], plus operation of multiple pantographs [16–18] and complex external loads on the components, including aerodynamic effects [19,20].

Electrification of legacy lines can prove problematic when a level crossing and overbridge are in close proximity. The height of overhead wires must be increased and lowered, respectively, to comply with the relevant gauging and safety standards. The variation of wire height is named wire gradients, and design optimization of these non-standard geometries can lead to a reduction of their adverse impact on pantograph-catenary interaction, thus allowing for higher train speeds. Furthermore, the improvements found may lead to cheaper and easier to deploy new electrification projects in critical areas.

The main aim of this work is to assess the pantograph-catenary dynamic performance at wire gradients, analysing the influence that different pantograph modelling approaches have on the current collection performance. For this purpose, Lumped-Mass (LM) and Multibody (MB) pantograph models are studied on catenaries with gradients. The pantograph considered in this study is the Brecknell-Willis HSX and the catenary models are based on the Network Rail Series 1 system. The numerical tool *PantoCat* is used to model the systems and evaluate their interaction via statistics of the contact force, such as force history and standard deviation (SD).

2 Methods

Two catenary models are developed in this work, based on the Network Rail Series 1 system, as installed on the Great Western Mainline. As per the system description manual, the nominal contact wire height is 4.70 m, the minimum wire height at overbridges is 4.16 m and the maximum wire height at level crossings is 5.94 m. At the design speed of 125 mph (200 kph), the maximum wire gradient allowed is 1:625, i.e., 1 metre of height variation per 625 m of track length. A catenary with constant wire height is also considered in this work, used as a baseline for comparison. The finite element meshes of both catenary models are depicted in **Figure 1**.

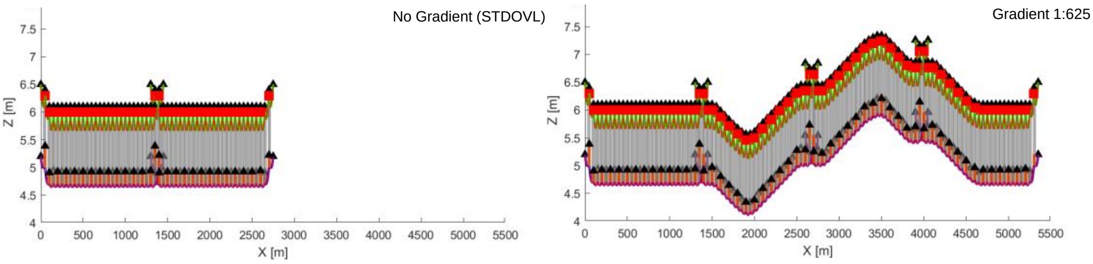
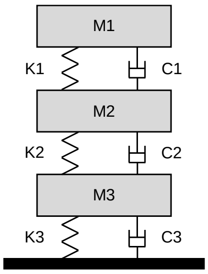


Figure 1: Comparison between catenary models with and without gradients.

The pantograph considered is the Brecknell Willis HSX, modelled using a lumped-mass as well as a multibody formulation. The LM model is a unidimensional, fully linear, three-stage system with masses, springs and dampers. The values of the relevant parameters have been determined experimentally by Deutsche Bahn in a specialised test bench [21], so that the frequency response of the LM model matches the dynamic behaviour of the real pantograph at given operational conditions, e.g., working height, frequency range and actuator force. The properties of the HSX LM model are 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: HSX LM model.

The MB methodology is a more realistic representation of the pantograph, describing each body and link individually. This methodology does not require a physical prototype of the pantograph, as technical drawings provide all the necessary geometrical data to assemble the system. It can also represent the nonlinear characteristics of the real pantograph, namely its varying dynamic response according to different operation conditions. Furthermore, it allows for the application of external loads applied on individual components, which are able to represent, for example, the aerodynamics of the real pantograph. The HSX MB model considered here is composed by 9 bodies, 9 joints, 7 spring-damper elements and 4 bumpstops.

Computational Fluid Dynamics (CFD) studies on HSX pantograph are performed, which allow to identify, for the 125 mph train speed, the aerodynamic forces acting on each component as a function of the pantograph working height. These forces include both the vertical aerodynamic uplift, and the horizontal drag. Conversely, the aerodynamics of the LM pantograph act on one mass, only vertically, and depend solely on the train speed, as per table 6 in EN 50367:2020 [22]. A 3D schematic view of the pantograph MB model is presented in **Figure 3**.

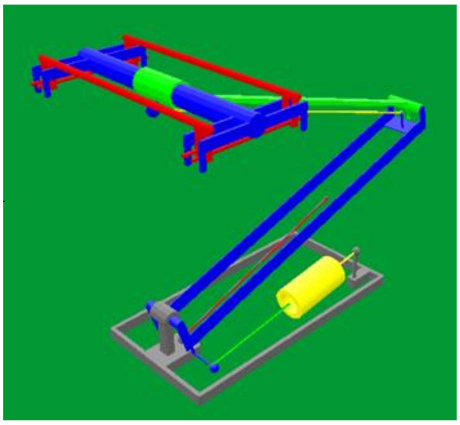


Figure 3: HSX MB model.

3 Results

The LM and MB pantograph models are analysed in two scenarios: STDOVL (baseline catenary including overlap), and G625 (model with 1:625 gradient). For each scenario, a train speed of 125 mph (200 kph) is considered. The contact force history for the LM pantograph on scenario G625 are presented in **Figure 4** and **Figure** 5, respectively without and with aerodynamic forces. The MB contact forces are presented in **Figure 6** and **Figure** 7. Each graph depicts the contact force filtered at 20 Hz (left axis), together with the contact wire height (right axis), both against track length. The catenary overlap zone, between wire runs, is highlighted in grey.

The results for the LM model illustrate its linear behaviour, i.e., same dynamic response regardless of pantograph opening range. This model is unaffected by the wire height variation. As the aerodynamic force only depends on train speed, it is also constant for this scenario and unaffected by the gradient. Consequently, the LM model with aerodynamics is also non-sensitive to wire height changes.

The MB model without aerodynamics behaves similarly to the LM model. However, the results of the MB formulation with aerodynamic loads on its components, which vary according on the pantograph extension, presented in **Figure 7**, show that when the pantograph reaches the overbridge, the contact forces decrease. When it approaches the level crossing, and the wire height grows, the contact forces increase, which is in line with the findings of experimental test runs performed in similar scenarios.

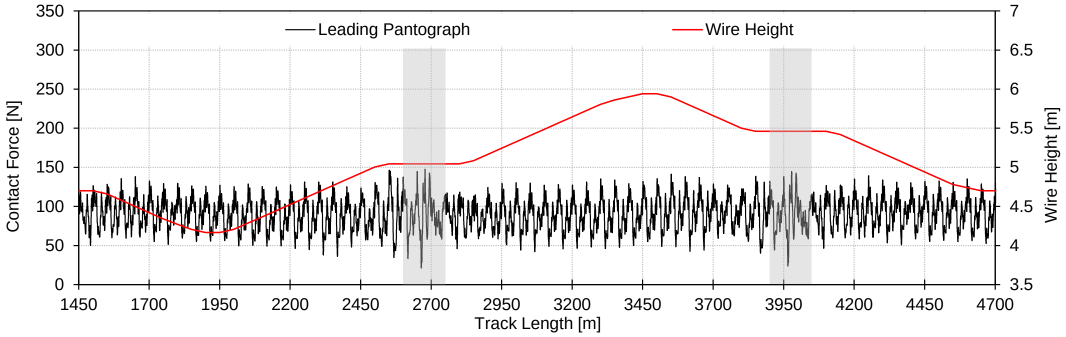


Figure 4: Contact force history for LM pantograph without aerodynamic forces

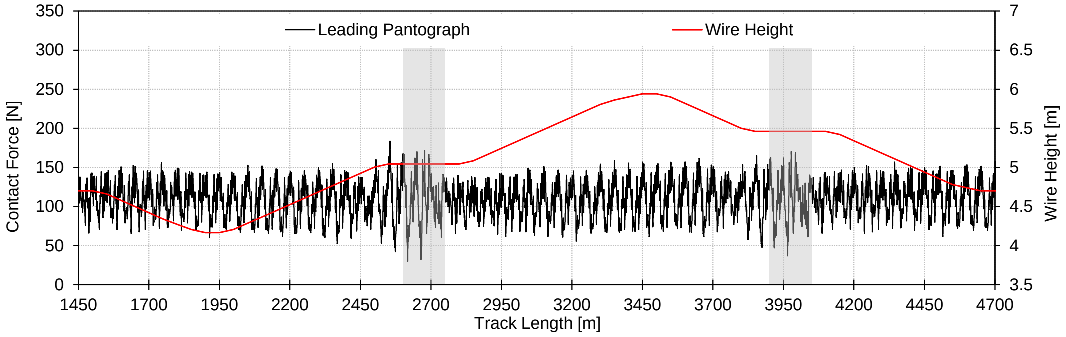


Figure 5: Contact force history for LM pantograph with aerodynamic forces

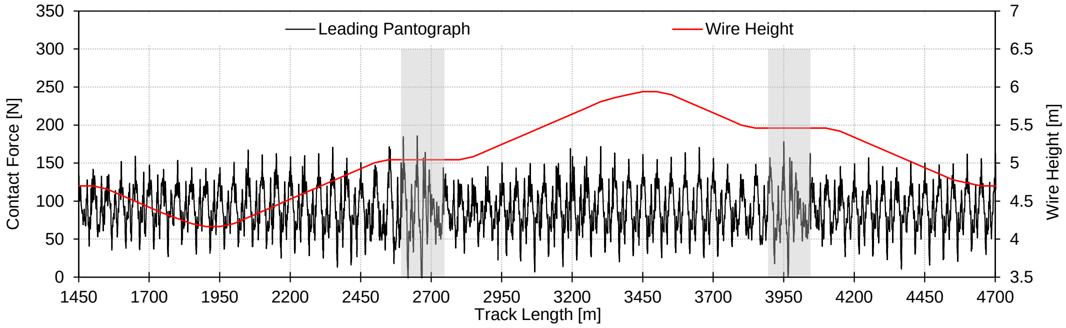


Figure 6: Contact force history for MB pantograph without aerodynamic forces

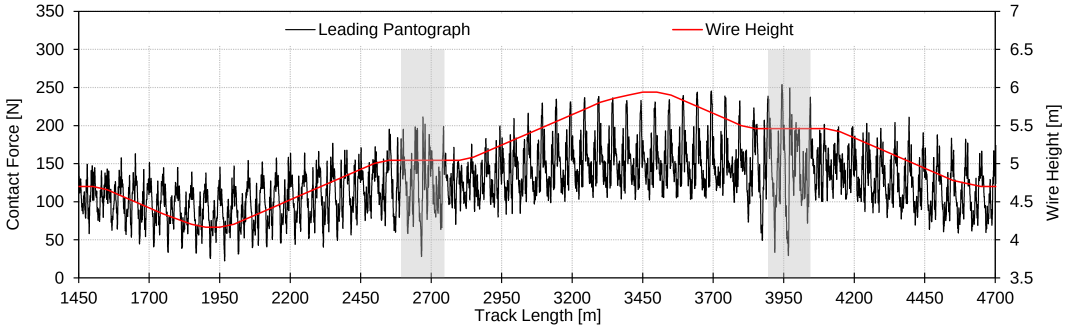


Figure 7: Contact force history for MB pantograph with aerodynamic forces

4 Conclusions and Contributions

This work presents a comparative study between the dynamic performance of a LM and a MB model of the HSX pantograph on catenaries with gradients. The results demonstrate that both formulations are almost non-sensitive to the contact wire height variations, even if aerodynamic forces are considered in the LM model. The contact force history also reveals a nearly constant contact force profile in catenaries with gradients. Consequently, the LM model is not suited for the analysis of pantograph-catenary interaction at non-nominal wire heights.

The pantograph MB modelling approach has the advantage of allowing the application of external forces, such as aerodynamic loads obtained via CFD studies, to each body of the model. These forces are separated into horizontal drag and vertical uplift. It is concluded here that the aerodynamic loads affect the pantograph-catenary interaction at gradients. The results demonstrate that the contact forces increase and decrease as the contact wire goes up and down, respectively, as a consequence of the variable pantograph extension. These outcomes align with the results obtained in experimental campaigns.

Future developments in this work include considering wind effects on the catenary wires and the validation of the MB results with aerodynamic effects against experimental data in relevant locations. Testing at different speeds is also of interest, in order to determine whether there is a minimum train speed at which the aerodynamics no longer play an important part in the pantograph dynamics.

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