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Pantograph-Catenary Interaction Dynamics with Aerodynamic Effects on Contact Wire Gradients

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EXTENDED ABSTRACT

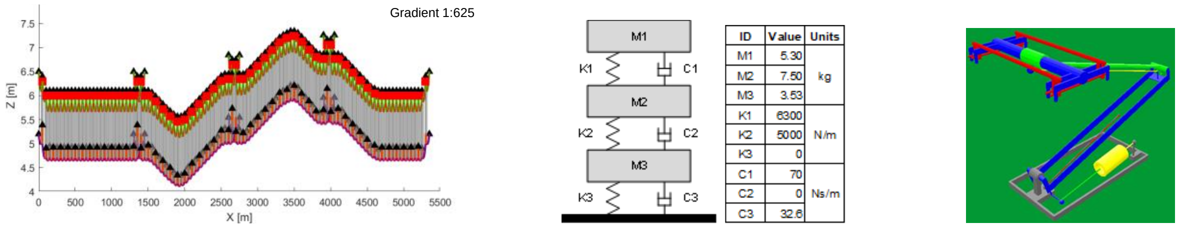
1 Introduction

On electrified railways the trains are powered via the pantograph-catenary system. Electrification of legacy lines can be challenging at level crossings and overbridges, as the catenary faces height variations (gradients), and suitable current collection must be assured. Improvements on pantograph and catenary design can lead to a reduction on the impact that these discrete features have on current collection performance, leading to higher operating speeds, maintenance 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 catenary 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 that vary according to the pantograph opening range. These aerodynamic forces are particularly important when studying catenary gradients, as the pantograph experiences higher drag and uplift forces as more extended it is. The developments presented here aid to optimize the design and reduce the costs of rail electrification projects by enabling to understand the current collection performance at different train speeds and gradient steepness.

2 Catenary Model

Two catenary models are developed in this work, based on the Network Rail Series 1 system, which is installed on the Great Western Mainline in the UK. 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 [1]. At the design speed of 125 mph (200 km/h), the maximum wire gradient allowed is 1:625, i.e., 1 metre of height variation per 625 m of track length. The finite element mesh of the catenary model is depicted in Figure 1.



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 1: Catenary model with a gradient of 1:625 (left); HSX LM model (middle), and; MB (right) pantograph model

3 Pantograph Model

The pantograph considered here is the Wabtec/Brecknell Willis HSX, which is modelled using a Lumped-Mass (LM) as well as a Multibody (MB) 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 [2], 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 1.

The MB methodology is a 3D realistic representation of the pantograph, describing the bodies, linking elements and suspension components individually, and assembling them together to represent the real pantograph. 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 pantograph, namely its varying dynamic response according to different operation conditions, e.g., working height, and roll and pitch motions of the head. Furthermore, it allows for the application of external loads applied on individual components, which represent, for example, the aerodynamics of the real pantograph. The HSX MB model depicted in Figure 1 comprises 9 bodies, 9 joints, 7 spring-damper elements, 1 actuator and 4 bumpstops [1].

Computational Fluid Dynamics (CFD) studies on HSX pantograph are also performed in this work. This approach allows to identify, for the 200 km/h train speed, the aerodynamic forces acting on each component of the pantograph as a function of its working height. These forces include the vertical aerodynamic uplift and the horizontal drag. Conversely, on the LM model, the aerodynamic effects are considered by applying a vertical force on one mass and depend solely on the train speed, as specified in Table 6 of EN 50367:2020 [3].

4 Dynamic Analysis Results

The results of the LM and MB models when running at 200 km/h on the catenary with 1:625 gradient, and without aerodynamic loads, demonstrate that both approaches are nearly non-sensitive to the contact wire height variations, which do not reproduce the behaviour that is experienced in service, where the interaction forces grow as the contact wire height increases and vice-versa. When aerodynamic forces are considered in the LM approach, by adding a constant uplift force to the model as specified in EN 50367:2020 [3], the results reveal that the contact forces continue to be marginally affected by the contact wire height variations, as depicted in Figure 2. Therefore, it is concluded that the LM model approach is not appropriate to study pantograph-catenary interaction at catenary gradients.

The MB methodology represents all component details of the pantograph and, therefore, aerodynamic loads can be explicitly applied to the pantograph parts and vary according to pantograph extension. The results obtained here when using the MB model with uplift and drag loads are presented in Figure 2. It is observed that the wind effects have a great influence on the current collection performance at wire heights variations, with the contact forces increasing at the level crossings and decreasing at low wire heights, reproducing the behaviour that is observed in rail operations when dealing with catenary gradients.

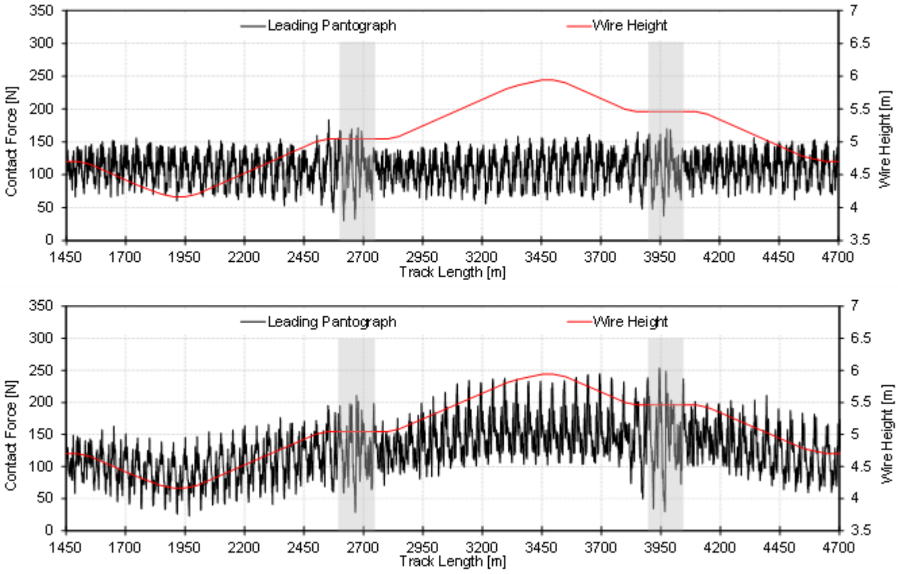


Figure 2: Contact force results on catenary with gradients for the LM (top) and MB (bottom) models with aerodynamic effects

5 Conclusions

This work presents a methodology to study pantograph-catenary interaction with contact wire gradients using the LM and MB formulations. The LM model is linear and unidimensional, which means that, according to the standards, the aerodynamic effects are considered by adding a constant uplift force defined for each operating speed. The results obtained here demonstrate that this methodology does not capture the dynamic response changes that occur when the contact wire height varies. So, it is concluded that the LM model approach is not appropriate to study pantograph-catenary interaction at gradients.

The MB approach is 3D and all main components of the pantograph are modelled. This allows to include in the formulation the aerodynamic loads that are applied on the pantograph parts, as function of the opening range and train speed. The results obtained here when using this approach with wind effects replicate the behaviour that is experienced in service when dealing with these overhead system height variations. This is a general methodology that can be used to study catenary gradients in any scenarios, which does not need to be customized to adapt/correlate with specific case studies and can be replicated elsewhere.

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