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A Study of the effect of contact wire curve on dropper static force and the contact quality of the pantograph and catenary at the overlap section

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Abstract

The interaction of pantograph and catenary is one of the crucial topics in train and infrastructure interaction, in particular when the new EMUs (Electric Multiple Units) are using multiple pantographs. One important parameter in the design of overhead contact line is the curve of contact wire. The curve of contact wire is defined by adjusting the length and consequently the static force (dead load) of droppers. Therefore, calculating the required dead load of droppers to achieve the demanded profile of contact wire, is a crucial step in any simulation model of pantograph-catenary interaction. In this study a precise analytical model of overhead catenary and pantograph has been developed and the effect of contact wire cure in the overlap section on the wave propagation in the mechanical section has been analysed. The study has focused on the German standard catenary and the results shows that abnormal static force in droppers between overlap point and tension wheel, can reduce the contact quality up to 20%.

Keywords: Pantograph, overhead catenary, dropper static load, wave propagation, wave reflection, contact quality.

1 Introduction

In the overhead catenary system, the length of droppers, or in other words, the static force of droppers plays an important role in pantograph catenary interaction. In fact, the length of droppers in the catenary influences the dynamic interaction of pantograph and catenary [1]. This influence is manifest in two aspects: 1- The contact wire curve (the vertical position of each point of contact wire), 2- The wave propagation and reflection, which are more critical at overlap sections. The demanded curve of the contact wire will determine the static force of each dropper [2], and the static force of each dropper will determine the ratio of the reflecting wave to the passing wave in the contact wire. Therefore, the demanded curve of the contact wire at the overlap section determines the wave propagation behavior of the contact wire indirectly, in particular at higher traveling speeds. This study aims to analyze the wave propagation behavior of standard catenary design at the overlap section and its effect on contact quality of pantograph and catenary system.

In this study, an analytical model of a German standard catenary (Re 250) is developed and its adynamic behavior at the overlap section has been analysed and compared in two scenarios. First, when the dropper's length, location, and contact wire curve are according to the initial design. Second, when one dropper has been shifted 50 cm and the contact wire has been maintained according to the design (Figure 1).

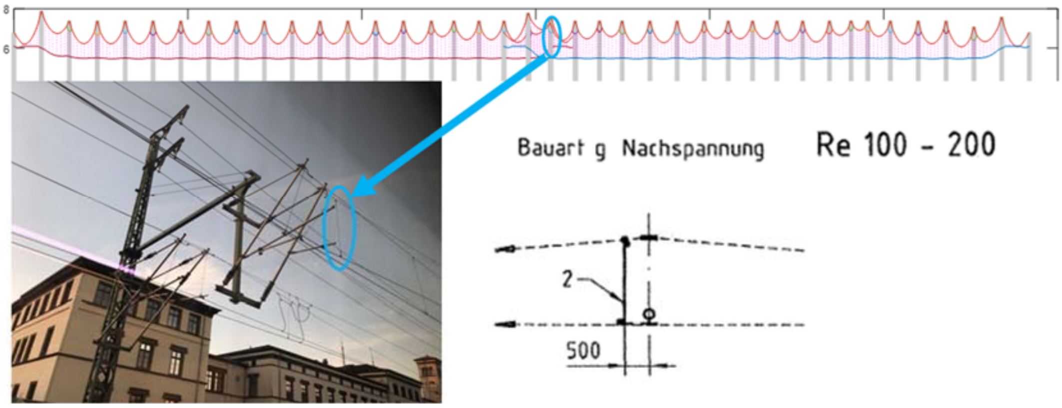


Figure 1 the shifted position of one dropper in the last span of a mechanical section that has been evaluated in this study

2 Methods

In this study, an analytical method, neither a Finite Element Method (FEM) nor a Finite Difference Method (FDM) has been applied for modeling and simulation [3]. Contact wire, messenger cable, and stitch wire are modeled as continuous tensile Euler Bernoulli beam and natural frequencies, and their mode shapes are calculated according to the eigenfunction expansion method, which is categorized under the continuous vibration theories. In fact, the contact wire and messenger cable of one mechanical section with almost 1Km length, have been modelled a two parallel tensile euler bernoulli beam and almost 1000 first mode shape of them have been considered in the calculation. With this approach, the authors can clime that the vibrations up to 40 Hz in cables have been considered.

$$\rho A_c wc_{,tt} + C_c wc_{,t} - P_c wc_{,xx} + EI_c wc_{,xxxx} = F_g + F_d(x) + F_p(x,t) + F_{ri}(x_s), \qquad 0 < x < l_c, t > 0 \quad (1)$$

In this equation, wc is the vertical deflection of the contact wire and subscribe shows n^{th} derivative of vertical deflection to time (t) and distance (x); ρA_c, C_c, P_c, EI_c are mass per unit length, structural damping coefficient, axial force, and bending stiffness of the contact wire respectively. F are forces and g, d, p, ri are addressing the force of gravity, dropper, pantograph, and registration arm respectively. The similar equation governs the dynamic motion of messenger cable too.

Droppers are non-linear elements, which have been modelled as a bi-linear stiffness spring and the bi-linearity threshold is calculated according to Buckling theory. Although the developed model is process intensive, it is more accurate in static form-finding (Figure 2).

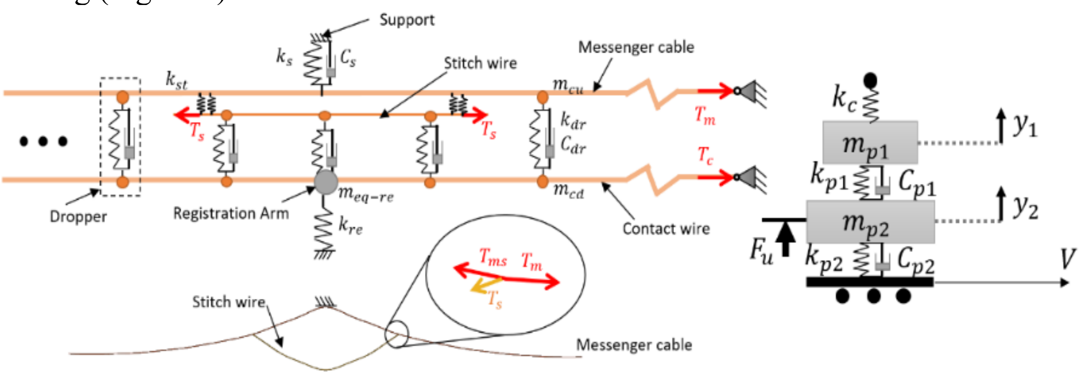


Figure 2 the mathematical model of overhead catenary and pantograph in this study

The details of this method are disclosed in the previous publication of the authors [2,4,5,6]. It should be noted that the pantograph has been modeled as a 2 degree of freedom spring-mass system since the main focus of this study is the dynamic behaviour of the overhead catenary system. The developed model is validated by the relevant standard. EN 50318 is a standard to validate the results of pantograph catenary simulation models. For each type of catenary, 4 levels of validation are applied, including validation with the static and dynamic result of a reference model and validating with static and dynamic results of field measurement.

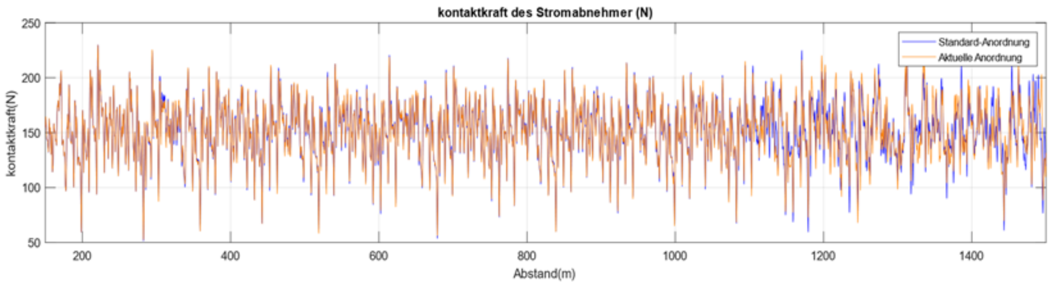
3 Results

The results of the model for both reference model and field test are within the acceptance range of standard and it proves that to result of this study is reliable.

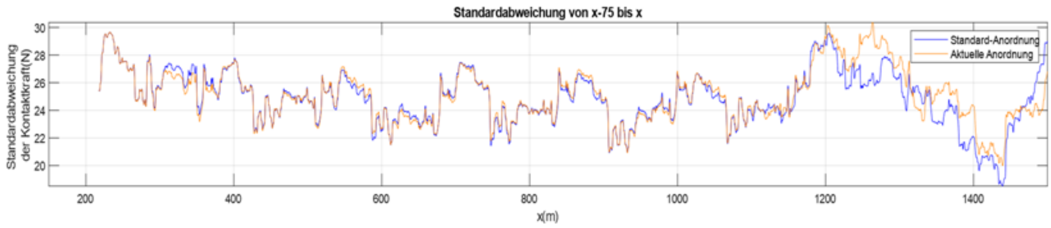
The static result of this study shows that three parameters are highly interdependent: Static force of droppers; demanded curve of contact wire; and the position of the dropper (i.e., the distance from previous dropper or mast). The result reveals that if the position of a dropper is shifted towards the mast, to keep the contact wire curve according to the standard design, the static force of droppers will increase significantly while the registration arm (or steady arm) will have a higher downward force consequently.

The dynamic result of this study shows that the contact quality of the pantograph and catenary is a function of wave (lateral wave) reflection at the end spans and this wave reflection is a function of the static force of droppers and registration arm. For example, in the case study of this project, the significant upward static force by a dropper besides a considerable downward static force of the registration arm, are making a fixed point that reflects all waves. It means the area between the tension wheel and overlap point, will have no direct impact on the dynamic interaction of pantograph and catenary, but it has a considerable impact on wave reflection and consequently, on the panto-catenary dynamic interaction.

This study shows that a 50 cm shift in the position of a dropper, marks a fixed point in the contact wire which can reduce the contact quality by 20% at end spans (Figure 3).



a)



b)

Figure 3 a) contact force between pantograph and catenary with normal arrangement and shifted arrangement of droppers, b) standard deviation of the contact force in normal arrangement and shifted arrangement

4 Conclusions and Contributions

In an overhead catenary system, mechanical sections are coupled together in overlap sections. From the operation point of view, the pantograph never meets the contact wire located between the overlap point and the tension wheel (i.e., the endpoint of the mechanical section). The result of this study shows that the contact quality (i.e. the standard deviation of contact force) is significantly influenced by the contact wire curve and droppers' static force at the area between the overlap point and the tension wheel. The generated wave due to a moving pantograph propagates in the catenary. Since there is no barrier or damper in the contact wire in the whole length of the catenary, the propagated wave can reach the end of the mechanical section. In this case, the simulation results showed that the droppers pass the upward waves and reflect downward waves.

The reason is behind the intrinsic behavior of droppers which are stiff under tension and soft under compression. Therefore, the propagated wave will be trapped at the end spans which are located between the overlap point and the tension wheel. In the studied case, a fixed point caused by a shifted dropper with abnormal static force relocates the trapping spans forward and the pantograph faces the reflected wave at the spanes close to the overlap section. Therefore, the contact quality is reduced up to 20% at the last spans.

Actually, this modeling and simulation was requested by DB Netz to evaluate the effect of a wrong installation scenario on the dynamic interaction of pantograph and catenary.

Acknowledgements

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