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Parametric model for the simulation of the railway catenary system static equilibrium problem

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ABSTRACT

Dynamic simulations of pantograph–catenary interaction are nowadays essential for improving the performance of railway locomotives, by achieving better current collection at higher speeds and lower wear of the collecting parts. The first step in performing these simulations is to compute the static equilibrium of the overhead line. The initial dropper lengths play an important role in hanging the contact wire at an appropriate height. From a classical point of view, if one wants to obtain the static equilibrium configuration of the system for different combinations of dropper lengths, one static problem must be solved for each combination of lengths, which involves a prohibitive computational cost. In this paper we propose a parametric model of the catenary, including the undeformed dropper lengths as extra-coordinates of the problem. This multidimensional problem is efficiently solved by means of the Proper Generalized Decomposition (PGD) technique, avoiding the *curse of dimensionality* issue. The capabilities and performance of the proposed method are shown by numerical examples.

1. Introduction

The overhead line equipment, or the so-called overhead catenary, is the system responsible for providing electric energy to railway locomotives by means of a pantograph. As a result of the pantograph–contact wire interaction and the dynamic response of the system, a contact force is generated which varies in time. The overhead line is designed to operate at the smallest possible contact force (to minimize wear due to friction) but maintaining at least a minimum value to ensure that the pantograph always remains in contact with the wire. The numerical models used to simulate this system are a useful tool in catenary design for achieving better high-speed current collection [1–3]. Fig. 1 shows the main elements of a typical railway catenary.

Many factors influence the dynamics of the overhead system and affect the contact force, these include dropper lengths, which are parameters that can be easily modified in engineering practice using the current catenary-stringing technology. The static position of the contact wire largely depends on the length and position of the droppers. Thus, the interaction of the pantograph with the contact wire and the contact force generated depends on the dropper lengths. In fact, some amount of the so-called presag of the contact wire (deviations of the contact wire height from the horizontal position) has been shown to improve catenary performance at high-speeds [4,5]. It is still an open question whether or not there is an optimal droppers length for a certain pantograph and train speed that provides the best performance in terms of contact force. Numerical simulation tools can help in solving this issue. However, at the present time, the analysis of the influence of undeformed dropper lengths on the dynamics of the system would require a great number of simulations for different combinations of these parameters, which would be unfeasible in practice with traditional finite element technology.

The aim of this paper is to present a numerical method able to perform this type of analysis at a reasonable computational cost. In particular, there is an especial interest in finding the static equilibrium position of the railway catenary system for any combination of dropper lengths. By using the Proper Generalized Decomposition (PGD) technique it is possible to solve parametric models that are defined in high dimensional spaces, such as in the problem at hand, in which undeformed dropper lengths are introduced as extra-coordinates.

PGD [6] is a Model Order Reduction (MOR) technique which can easily solve multidimensional problems. PGD has already successfully addressed a variety of problems, including shell-type geometries [7,8], shape optimization problems [9], computational rheology [10], linear elastic fracture mechanics [11] or mechanic simulation for biological tissues [12,13] among others, in a

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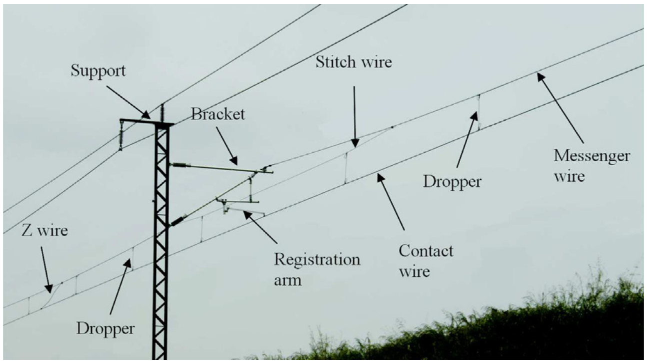

Fig. 1. Photo of a high-speed train catenary.

multidimensional framework. Space–time decompositions are dealt with in [14] under a PGD approach. The errors of the PGD solutions are studied in [15]. PGD is thus able to provide a multiparametric solution of the problem that explicitly depends on the parameters to be identified (in this case dropper lengths) and avoids the *curse of dimensionality* issue when a large number of parameters are considered. The interested reader is addressed to [16] and the references therein for a deeper analysis of this aspect.

The main interest of the proposed method is to obtain a solution of the static equilibrium position, required to simulate the dynamic interaction, for any combination of dropper lengths. With the parametric solution it is possible to perform an efficient geometry optimization process of the catenary, based on different criteria, such as the minimal standard deviation of the contact force. With a parametric dynamic solution of the problem, the effect of wrong stringing, which leads to a static configuration other than the one designed, can be reproduced and analyzed.

The paper is organized as follows. The overhead line and the elements which compose the catenary are described in Section 2. In Section 3 the finite element model of the catenary is introduced. This model is based on the absolute nodal coordinate formulation (ANCF). On the basis of the virtual work principle, in Section 4, the static equilibrium problem is presented from a classical point of view. In Section 5 the static equilibrium problem is dealt with the PGD approach. The proposed formulation is given in two versions: (i) without considering dropper slackening and (ii) including the effect of dropper slackening. A linearized problem is also presented in order to reduce the computational cost. The accuracy and performance of the method is analyzed in Section 6 through some numerical examples. Finally, the conclusions are summarized in Section 7.

2. Description of the overhead line

Fig. 1 shows a high-speed train catenary. The catenary is mainly composed of two groups of components, structural elements and cables. Masts, brackets and registration arms are responsible for supporting the entire cabling in the desired position. The cables include the messenger or carrier wire, droppers and contact wire. The messenger wire hangs from the brackets at regular intervals. Its main aim is to hold the contact wire at the required height from the track. This can be achieved by means of droppers clamped to the messenger and contact wire at certain points in every span. The contact wire transmits electrical power to the locomotive through the pantograph head on the locomotive roof. Some types of catenaries include stitch wires near the masts in order to reduce the variation of the stiffness along the span. Both the messenger and contact wires are prestressed and keep the tension constant with the aid of a compensation system located at both ends of each section along the overhead line.

Viewed from the above, the catenary follows a zigzag pattern from one bracket to another. This stagger is designed to guarantee uniform wear on the contact strip of the pantograph collectors. Another important geometric issue in many catenaries is their presag, which reduces the variations in contact force caused by the reduced stiffness in the central region of the spans, and is controlled by means of appropriate dropper lengths.

It is important to point out that small changes in certain parameters, such as the undeformed dropper lengths, may change the height of the contact wire and therefore affect interaction with the pantograph. Also, if the initial length of a dropper is larger than a certain value, the dropper can slacken and fail to hold the contact wire in the static position.

3. Catenary finite element model

The catenary system was modeled by finite elements. Only the main features of the model are summarized here (for further information see [17]). An example of this model is depicted in Fig. 2, in which the nodes are plotted as circles. A beam element based on the absolute nodal coordinate formulation (ANCF) is employed to model the cables. The original 3D ANCF element was proposed in [18,19] and used for railway catenary models in [20,21]. For the interested reader, a good comparison between this element and the elements based on the classical formulation can be found in [22].

Catenary wires are much longer than their cross-sectional area, so that the torsional effects can be neglected. This results in the element introduced in [23] with only 6 degrees of freedom per node, taking into account axial and bending deformations. In this paper, this type of element is called a 'cable element' and is used to model both the messenger and the contact wires. Droppers and registration arms are modeled as a single large displacement nonlinear element called a 'bar element' throughout the paper. The bar element is only capable of transmitting axial forces in traction and slackens under compressive forces.

In this model the masts and brackets are replaced by suitable boundary conditions. Dirichlet boundary conditions are applied at the ends of the registration arms joined to the brackets (nodes marked with a cross in Fig. 2). Spring-damping elements are used to simulate the supports (nodes marked with a square in Fig. 2).

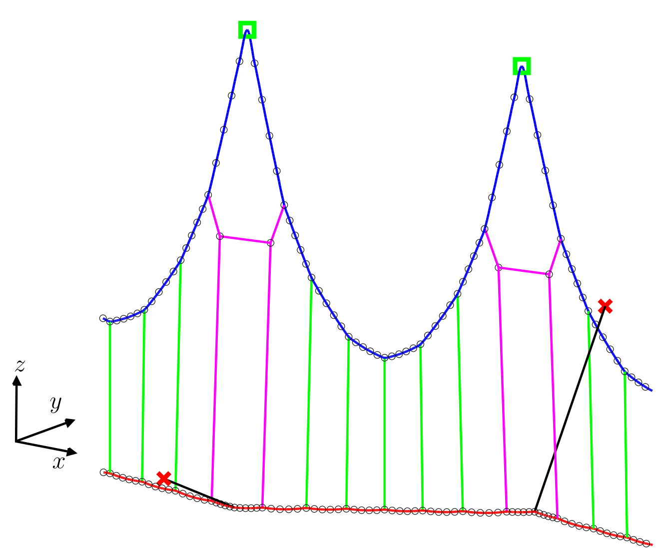

Fig. 2. Finite element model of the catenary.