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An advanced 3D-model for the study and simulation of the pantograph catenary system

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A B S T R A C T

Catenary systems of modern railways are designed to allow the contact wire to operate satisfactorily over the full extent of the carbon-rubbing strip of the pantograph and to obtain optimum operating conditions, with the goal of developing high running speeds with minimal maintenance cost. In order to obtain suitable results, we must develop realistic mathematical models that allow us a very faithfully simulation of the system behavior, with a low computational cost at runtime. The work here presented is an extension of a previous method presented by the authors, but considering now a three-dimensional model. This new version allows us a more realistic simulation, and includes some details not found in traditional models, as it is the lateral displacement of the contact wire, or a lateral wind load actuating on the catenary. Furthermore, the dynamic equations of the pantograph has been formulated newly, considering this pantograph as an articulated multibody system, by using independent coordinates and symbolic computation. Finally, these equations have been implemented in a high performance computing tool called InDiCa3D.

1. Introduction

In the transport and electricity supply in modern railways, the Overhead Contact Line, also known as catenary, is one of the most used systems. This railway catenary is a structure made of a complex system of cables that provides the electrical energy supply to the train by means of the contact between the pantograph, located in the drive unit of the vehicle, and the catenary itself. In its simplest form, the catenary consists of three main components. The contact wire supplies the electrical energy to the train, the messenger wire provides sufficient stiffness to the catenary and the droppers link both wires.

Catenary systems are designed to allow the contact wire, usually of copper, to operate satisfactorily over the full extent of the carbon-rubbing strip of the pantograph. Contact wires and overhead line are flexible systems that are subjected to oscillations that have to be compensated for a satisfactory quality of current collection avoiding contact losses. Thus, for this reason, to obtain optimum operating conditions, where the contact force between pantograph and catenary should be kept as uniform as possible, avoiding takeoffs or lost contact, has undergone profound attention in recent years in the scientific literature. The ultimate goal of these studies is to develop high running speeds with minimal maintenance cost.

In the literature on the subject, we can found mathematical models which are developed to simulate the operation of the system, obtaining, in this way, some conclusions which would be much more costly to achieve through real trials. Different procedures have been proposed for the study of the problem. Thus, in Arnold and Simeon (2000) a method based on coupled

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systems of partial and algebraic differential equations is presented, in Balestrino et al. (1998) we can find a simplified model for the study of the performance of the pantograph, in Collina and Bruni (2002) there is a procedure based on penalty techniques and modal analysis, while Rauter et al. (2007) introduces a procedure using an articulated multibody model for the pantograph and co-simulation techniques. In Seo et al. (2005) we have a study done by absolute nodal coordinates and elements with large deformation. Finally, in Zhang et al. (2002) it is proposed a hybrid theoretical–experimental method by using modal analysis with a real pantograph.

In order to obtain suitable results, we must develop realistic mathematical models that allow us a very faithfully simulation of the system behavior, with a low computational cost at runtime. The existence of nonlinearities in the mathematical equations produced by takeoffs in the pantograph, especially when it interacts with several catenary contact wires or with overlapping spans, as well as those produced by the existence of the slackening of the droppers are difficult issues to resolve. Those problems are not generally treated with sufficient detail in the literature. These difficulties increase when considering more advanced three-dimensional mdels. In this sense, the model proposed in Alberto et al. (2008) based on the method of integration of central differences has proven particularly suited, because it allows to obtain very efficient simulations, resolving these difficulties.

In this work, the model adopted for the catenary has been based on the Finite Element Method, while for the pantograph a model based on the complete dynamics equations as an articulate multibody system was adopted. Thus, the work here presented is an extension of the method presented in Alberto et al. (2008), but considering now a three-dimensional model. This new version allows us more realistic simulations, and includes some details not found in traditional models, as the lateral displacement of the contact wire, or a lateral wind load actuating on the catenary. Furthermore, the dynamic equations of the pantograph has been newly formulated, considering this pantograph as an articulated multibody system, by using independent coordinates and symbolic computation, which can be done by means of the vast computing power that can perform in this area by symbolic computing systems such as Mathematica or MATLAB. With this help, we have also established equivalence relations between the actual bar linkage model, and the lumped masses model traditionally used in these kind of simulations.

The proposed method can also solve other variety of problems related to static assembly, and installation of catenary systems, as calculating the droppers. This problem consists in calculating the length of these droppers (vertical catenary wires) in order to obtain a particular configuration desired in the contact wire (cable where contact is made with the pantograph). The study of this problem is closely related to dynamic problems by allowing simulations on different possible values ranging in catenary mounting: mechanical tension in the wires, deviations on the contact wire, number of droppers, etc., as well as different types of catenary can be studied: normal span, or stitched catenary, in order to validate certain values for the assembly.

The paper is organized as follows. Section 2 describes the model we are using, presenting the model of the catenary and the droppers, and afterwards, defining the static equilibrium equation of the catenary, for the calculation of the length of the droppers. Section 3 provides also the model of the pantograph. Both models allows us to present the pantograph/catenary interaction model in Section 4, which is solved, by means of the corresponding algorithm in Section 5. In next section, InDiCa3D tool is fully explained, including some experimental results. And finally, in Section 7, the main onclusions and future works of this study are drawn.

2. Catenary model

2.1. Catenary wire, stitched wire and contact wire model

The overhead contact line or catenary is installed considering a sequence of spans (line span), where each series comprises an independent system of 15–20 spans considering that the span length is around 60 m. in European railways. Two types of catenaries can be considered: the normal catenary and the stitched catenary. A span of stitched catenary is shown in Fig. 1. In this figure, four kinds of cables are used: the catenary wire, the stitched wire, the contact wire and the droppers. The catenary wire, the stitched wire and the contact wire are tightened by an independent system of pulleys and weights. Therefore, the catenary is a continuous system that can be modeled using Finite Element Method techniques, according to Cook et al. (1989).

Assuming the most accepted hypothesis of small deformations, the model for the wires is obtained from the Euler–Bernoulli equation for a prestressed beam (more details about this model can be found in Cook et al. (1989)). In the 3D model these elements are loaded by their weight and by the lateral action of the wind. An element of wire, shown in Fig. 2, presents four generalized coordinates according to the node: vertical displacement along the *OY* axis, turning angle in the plane *OZX*, lateral displacement along the *OZ* axis and turning angle in the plane *OXY*. The static equilibrium equations for an element of a three-dimensional cable is a lineal system of eight equations and it can be considered as an extension of the simpler two-dimensional model shown in Alberto et al. (2008).

2.2. Dropper model

The droppers are elements formed by cables. Thus, they can only perform by traction; and so, when a traction force is acting, they behave exactly like a bar, but when there is a compession force, the droppers are not acting, and its effect has to be discarded in the stiffness matrix.