A multibody approach for the simulation of ropeway systems

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EXTENDED ABSTRACT

1 Introduction

Ropeway systems are gaining ground as transportation means in urban environments. Their manufacturers claim that such systems relieve the environment with low energy costs and low emissions. Proper and efficient design of these systems urges the need for a dynamic model for ropeway systems, which is not available so far. While there already exist computational frameworks for the computation of the static configuration, the dynamic problem of the rope with cabins in contact with sheaves and rollers is not straightforward. The multibody system model has the potential to investigate and predict its dynamic behavior in the design phase with the possibility to increase comfort in urban applications. This work aims to develop a planar dynamic model with physical parameters including contact between rope and sheaves and cabins attached which can be simulated using an implicit time integrator within a few minutes.

Few studies exist on the modeling and simulation of ropeway systems. Existing literature is focusing on the dynamic effect of cross-wind and other influences, [1, 2]. A few recent works are studying the dynamic response of roller batteries, [3, 4]. However, very limited research has been conducted on the detailed numerical modeling and efficient simulation of the dynamics of the rope interacting with the dynamics of the cabins and in contact with rollers.

2 Mechanical and Numerical Modeling

We are modeling the system using a special finite element for the rope and a multibody dynamics framework which allows us to integrate the cabins and the roller batteries, see Figure 1. The numerical modeling of the rope is based on the Absolute Nodal Coordinate Formulation (ANCF), [5]. An alternative approach would be the ALE ANCF beam element proposed in [6], which can be used for ropeway systems with masses distributed along the rope.

As a crucial part of the simulation model, an efficient contact between sheaves or rollers and the rope has to be implemented. As main tool of the contact implementation, we use boxed search for more than 100 rollers and potentially 1000s of beam elements to model the rope. Contact between the rollers in roller batteries and the rope is modeled through a normal contact model based on the penalty formulation and a regularized Coulomb friction model. The special geometry of the system which consists of cubic polynomials that interpolate the nodes of the rope and circular objects allows us to compute the contact points of the two bodies as the numerical solution of the exact geometrical problem. For the contact of the rope with the sheaves, the modeling of the friction is crucial for the transmission of the motion from the driving sheave to the system. A so-called bristle model, often used in control engineering [7], has been previously used for reeving systems [8]. In this work, the bristle model has been significantly extended with respect to history variables that do not require to introduce an additional dynamic parameter [7]. It has also been extended from a point-to-circle contact to a segment-to-circle contact, which reduces the polygon effect [9]. Finally, this friction as well as the penalty contact model have been adjusted for being compatible with an implicit time integration.

3 Ropeway System Simulation

The ropeway system of Figure 1 is simulated in the multibody dynamics code EXUDYN [10]. Because the major part of the relevant system components moves in a plane, we reduce the system to a planar model. Sheaves A and B are used to model the upper and lower station, however, the axis of sheaves A and B are rotated by 90° around X, as in reality the sheaves' axes would coincide with coordinate Y, see Figure 1(a). Cabins are modeled as rigid bodies connected to the rope through revolute joints.

The roller battery mechanism and the large number of rollers cause a significant increase in the complexity of the simulation model, see Figure 1(b). For this reason, we investigate if the roller batteries can be simplified by single sheaves. In the latter simplified case, the single sheaves obtain approximately the radius as given by the arc of the rope within each roller battery in the initial configuration. While such a model does not allow us to study the vibrations of the cabins over passing the towers, it is still possible to approximate the overall system dynamics. The complex and the simplified models are studied regarding the overall dynamics and the motion of the cabins.

For the dynamic simulation, an according initial (static) configuration is needed, considering the rope and cabins under gravity as well as the contact with rollers and sheaves within a nonlinear static problem. For this static problem, an initial static guess is needed, as well. As a simplified but robust initialization, we use the geometry of the idealized reeving system without gravity. The reeving system consists of the sheaves, roller batteries – simplified as sheaves – and virtual sheaves between each tower, the latter in order to incorporate an initial sag of the rope, see Figure 1(c).

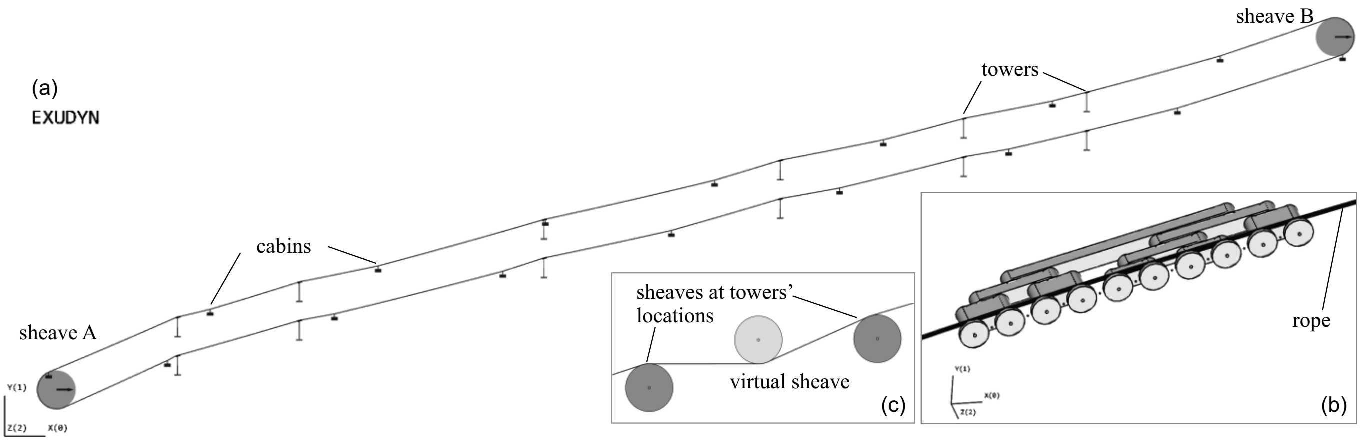

Figure 1: (a) Simulated ropeway system. (b) Detailed figure of roller battery (without a tower drawn) used during simulation. (c) Reeving system consisted of sheaves at the location of the towers (in dark grey) and virtual sheaves (in light grey).

4 Conclusions and Outlook

In this work we will show that the ropeway systems can be simulated as a fully coupled multibody system considering the roller batteries and cabins, including contact and friction between rope and sheaves. We will show parameter studies, where we will vary the rope velocity as well as the cabin masses, which are important design parameters in the system.

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