Comparison between Multibody and lumped-mass pantograph models for the analysis of pantograph - overhead line interaction

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Abstract

The analysis of interaction forces between pantograph and rigid overhead conductor lines requires the discretization of the overhead structure as a Finite Element Model. As a consequence, coupling its dynamic behaviour to that of the pantograph is easiest when the latter is represented by a number of concentrated masses connected by springs and dampers (Fig. 1). The coupled equations of motion have the following structure:

$$\begin{bmatrix} \boldsymbol{M}_c & 0 & 0 \\ 0 & m_1 & 0 \\ 0 & 0 & m_2 \end{bmatrix} \begin{Bmatrix} \ddot{\boldsymbol{q}}_c \\ \ddot{y}_1 \\ \ddot{y}_2 \end{Bmatrix} + \begin{bmatrix} \boldsymbol{C}_c + c_c \boldsymbol{N}\boldsymbol{N}^T & -c_c \boldsymbol{N} & 0 \\ -c_c \boldsymbol{N}^T & c_c + c_1 & -c_1 \\ 0 & -c_1 & c_1 + c_2 \end{bmatrix} \begin{Bmatrix} \dot{\boldsymbol{q}}_c \\ \dot{y}_1 \\ \dot{y}_2 \end{Bmatrix} + \begin{bmatrix} \boldsymbol{K}_c + k_c \boldsymbol{N}\boldsymbol{N}^T + V(t) c_c \boldsymbol{N}\boldsymbol{N}_x{}^T & -k_c \boldsymbol{N} & \boldsymbol{0} \\ -k_c \boldsymbol{N}^T - c_c V(t) \boldsymbol{N}_x{}^T & k_c + k_1 & -k_1 \\ \boldsymbol{0} & -k_1 & k_1 + k_2 \end{bmatrix} \begin{Bmatrix} \boldsymbol{q}_c \\ y_1 \\ y_2 \end{Bmatrix} = \begin{Bmatrix} \boldsymbol{0} \\ kV(t)^2 \\ F_2 \end{Bmatrix} \quad (1)$$

Where $\mathbf{M}_c$, $\mathbf{C}_c$, $\mathbf{K}_c$ are the catenary mass, damping and stiffness matrices, respectively; $\mathbf{N}$ is the shape function vector; $\mathbf{q}_c$ are nodal displacements; y_1 and y_2 are the lumped masses displacements (dotted variables represent the corresponding derivative with respect to time); m_1 and m_2 are the lumped masses, and k_1, k_2, kc, c_1, c_2 and c_c are the spring and damping rates of the pantograph model shown in Figure 1; V(t) is the train speed and k is the aerodynamic factor. The numerical solution of these equations only differs from standard FEM dynamic equations in that the contact force needs to be monitored (evaluated) at each time step to detect possible detachments.

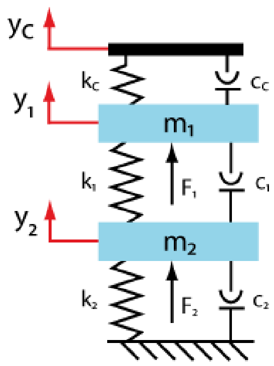

Figure 1: Lumped mass pantograph model.

On the other hand, when the pantograph is modelled as a multibody (MB) linkage (Fig. 2), the problem becomes more complicated, the catenary FEM model and the pantograph MB model need to be integrated independently but taking into account the fact that the excitation force is the same (although in different directions) for both of them. The proposed co-simulation algorithm (Fig. 3) estimates the force in the next time step and iterates (with frozen simulation time) to make the estimation compatible with dynamic equilibrium. An initial rough estimation of the contact force at time $t+\Delta t$ can be obtained by assuming that the pantograph has advanced to its next location whereas all displacements and velocities remain unchanged. The estimated contact force is used to integrate the equations of motion and, in turn, re-evaluate the contact force. The loop is repeated until the contact force stabilizes.

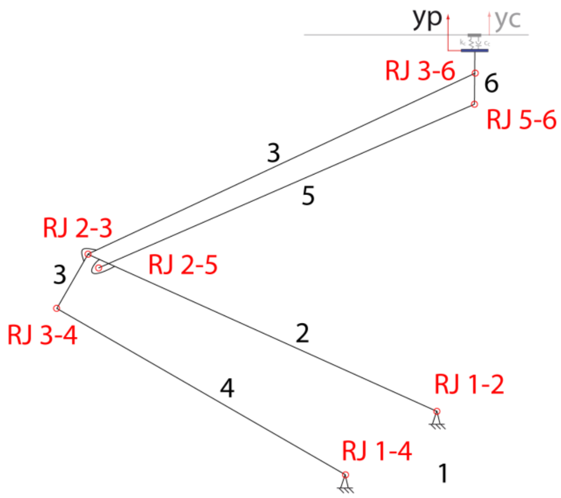

Figure 2: Pantograph multibody schematics. Numbers differentiate each body, and labels RJ i-j refer to “Revolution Joint” between solids i and j.

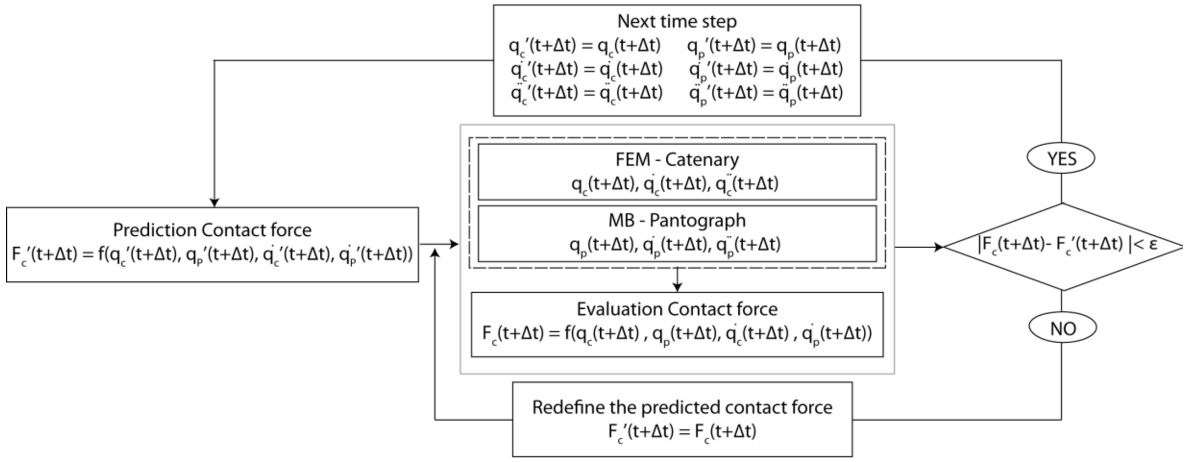

Figure 3: Co-simulation algorithm.

The paper analyzes the differences between contact force records obtained using the two approaches outlined in the previous paragraph. Appropriate parameters for the lumped mass (LM) model may be found from the potential and kinetic energies of the MB linkage. It will be shown that both models produce very similar results and, therefore, the simpler LM model could be used for infrastructure design and optimization. Nevertheless, it will also be shown that the MB model is unavoidable when the objective is pantograph optimization.

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