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Effect of multiple pantographs on their dynamic interaction with a catenary system

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The collection of electric current during the operation of electric rail vehicles is provided by pantographs, which should be in contact with a catenary system conducting current. The motion of the vehicle with pantographs causes various dynamic effects related to the interaction of pantographs and catenaries. It is the issue for all types of vehicles ranging from low-speed trams to high-speed trains. The authors of this paper started to develop the in-house DynPAC software for the analysis of the dynamic interaction between catenary systems and pantographs [1]. The main problem was to create the software in order to fulfil the requirements of particular European Standard EN 50318:2002 called "Railway applications – Current collection systems – Validation of simulation of the dynamic interaction between pantograph and overhead contact line" [2]. This standard defines a special benchmark problem and criteria on numerical results in order to validate developed software tools. Currently, new edition of this standard EN 50318:2008 is valid and brings many new requirements on the simulation software. As a results of this standard update, the authors developed the DynPAC 3 software reflecting the substantial changes of the standard. This paper deals with the dynamical analysis of two pantographs running on one catenary system and with the effects of various operational and design parameters on this interaction.

Main components of the catenary system are shown in Fig. 1. Static problems have to be solved in the course of catenary system design. It is affected by a tension of particular wires, by the gravity force acting on the wires and mainly by the length of droppers. The modelling approach used in this paper applies the discretization of the wire by the beam finite

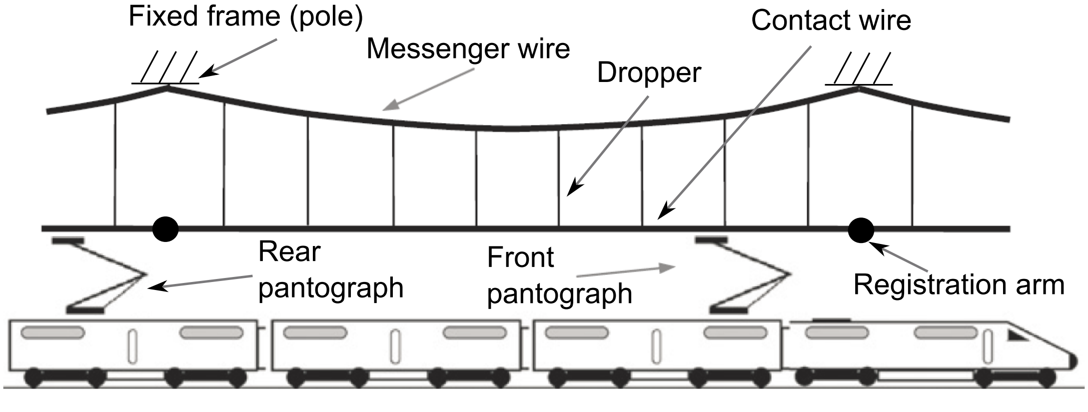

Fig. 1. Scheme of a general pantograph-catenary problem with its main components

elements with two nodes [3] and respecting bending and pretension of the wire. The whole mathematical model of the pantograph-catenary system, which is the basis of the DynPAC software, is assembled in this form

$$\begin{bmatrix} \mathbf{M}_{pF} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{M}_{pR} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{M}_{cw} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{M}_{mw} \end{bmatrix} \begin{bmatrix} \ddot{\mathbf{q}}_{pF} \\ \ddot{\mathbf{q}}_{pR} \\ \ddot{\mathbf{q}}_{cw} \\ \ddot{\mathbf{q}}_{mw} \end{bmatrix} + \begin{bmatrix} \mathbf{B}_{pF} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{B}_{pR} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{B}_{cw} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{B}_{mw} \end{bmatrix} \begin{bmatrix} \dot{\mathbf{q}}_{pF} \\ \dot{\mathbf{q}}_{pR} \\ \dot{\mathbf{q}}_{cw} \\ \dot{\mathbf{q}}_{mw} \end{bmatrix} +$$

$$+ \begin{bmatrix} \mathbf{K}_{pF} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{K}_{pR} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{K}_{cw} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{K}_{mw} \end{bmatrix} \begin{bmatrix} \mathbf{q}_{pF} \\ \mathbf{q}_{pR} \\ \mathbf{q}_{cw} \\ \mathbf{q}_{mw} \end{bmatrix} = \begin{bmatrix} \mathbf{f}_{pF} \\ \mathbf{f}_{pR} \\ \mathbf{0} \\ \mathbf{0} \end{bmatrix} + \begin{bmatrix} \mathbf{0} \\ \mathbf{0} \\ \mathbf{f}_{cw} \\ \mathbf{f}_{mw} \end{bmatrix} + \tag{1}$$

$$+ \begin{bmatrix} \mathbf{0} \\ \mathbf{0} \\ \mathbf{f}_{dr}^{(cw)}(\mathbf{q}_{cw}, \mathbf{q}_{mw}) \\ \mathbf{f}_{dr}^{(mw)}(\mathbf{q}_{cw}, \mathbf{q}_{mw}) \end{bmatrix} + \begin{bmatrix} \mathbf{f}_{c}^{(pF)}(\mathbf{q}_{pF}, \mathbf{q}_{cw}) \\ \mathbf{f}_{c}^{(pR)}(\mathbf{q}_{pR}, \mathbf{q}_{cw}) \\ \mathbf{f}_{c}^{(cwF)}(\mathbf{q}_{pF}, \mathbf{q}_{cw}) + \mathbf{f}_{c}^{(cwR)}(\mathbf{q}_{pR}, \mathbf{q}_{cw}) \\ \mathbf{0} \end{bmatrix}.$$

Variables denoted by $\mathbf{M}$ are mass matrices, $\mathbf{B}$ are damping matrices and $\mathbf{K}$ are stiffness matrices. Vectors $\mathbf{q}$ are vectors of generalized coordinates. Pantographs are indicated by subscript pF for front and pR for rear pantograph. They are represented by lumped models with two or three degrees of freedom according to the standard. Force vectors $\mathbf{f}_{pF}$ and $\mathbf{f}_{pR}$ contains designed uplift forces of pantographs. Finite element matrices of pretensioned wires are denoted by subscripts cw for contact wire and mw for messenger wire. Vectors $\mathbf{f}_{cw}$ and $\mathbf{f}_{mw}$ represent gravity load of the wires, while vectors $\mathbf{f}_{dr}^{(cw)}$ and $\mathbf{f}_{dr}^{(mw)}$ represent nonlinear dropper forces between both wires. The interaction between pantographs and contact wire is described by nonlinear force vectors $\mathbf{f}_c$ with particular superscripts. The contact forces act on the contact wire as a moving load with the defined speed of the train. This huge system of nonlinear equations of motion have to be numerically integrated in time. The implemented software allows to automatically create the finite element mesh of the wires and also to evaluate the important results of the numerical solution with respect to the standard. The simulation results are used for the evaluation of the effects of various operational and design parameters on the contact force, motion of pantographs and vibration of wires.

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References

[1] Hajžman, M., Očenášek, J., Benchmark problem for the pantograph and catenary numerical simulations, Proceedings of Colloquium Dynamics of Machines, Prague, Institute of Thermomechanics AS CR, 2014, pp. 37-44.

[2] EN 50318:2002 Railway applications – Current collection systems – Validation of simulation of the dynamic interaction between pantograph and overhead contact line, International Technical Standard, 2002.

[3] Przemieniecki, J. S., Theory of matrix structural analysis, Dover, New York, 1985.