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State sensitivity analysis of the pantograph system for a high-speed rail vehicle considering span length and static uplift force

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Abstract

In this paper, dynamic characteristics analysis of catenary and pantograph systems for a high-speed rail vehicle is carried out. The catenary system is considered to be a beam model. The analysis of the catenary based on the finite element method (FEM) is performed to develop the pantograph. The stiffness value can be obtained at each nodal point on the contact wire. State sensitivity analysis was executed with respect to design variables considered by the pantograph system. The pantograph of linear spring–mass–damper system is considered as a 3dof model using lumped parameters. Dynamic modeling of the pantograph system is verified by actual experimental vibration data. To perform the sensitivity analysis, our study was considered lift force effect of the pan-head occurring at high-speed runs. Also, a span length and static uplift force were included into design variables. As a result, we could confirm that span length and plunger spring constant are some of the important design variables of catenary and the pantograph systems.

1. Introduction

At present, the high-speed railway that is the next generation of transportation system is characterized by high stability, high driving velocity, and ride comfort as compared to the other transportation systems. An accompanying problem of the high speed of the railway is ensuring stable current collection. For stable operation of a railway, the catenary must be supplied with stable electrical power through solid contact with the pantograph. When the railway speed is increased, contact loss will occur between the pantograph and the catenary due to the catenary stiffness. In addition, wear on the pantograph is going to grow as electrical shock and damage may occur [1]. Therefore, research into understanding the current-collecting system's dynamic

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Nomenclature

m_1	mass of the pantograph frame
m_2	mass of the pantograph plunger
m_3	mass of the pantograph pan-head
c_1	damping coefficient between the vehicle body and the frame
c_2	damping coefficient between the frame and the plunger
c_3	damping coefficient between the plunger and the pan-head
k_1	stiffness coefficient between the vehicle body and the pantograph frame
k_2	stiffness coefficient between the frame and the plunger
k_3	stiffness coefficient between the plunger and the pan-head
L	a span length
F_1, F_2, F_3	static uplift force of the pantograph
F_{L1}, F_{L2}, F_{L3}	lift force
y_1	vertical displacement of the upper and lower arm
y_2	vertical displacement of the crossbar and plunger
y_3	vertical displacement of the pan-head
d_1^e, d_3^e	vertical displacement of the contact wire and the messenger wire
d_2^e, d_4^e	angle of rotation of the contact wire and the messenger wire
h	length of one finite element of the wire
K_{ew}	element stiffness matrix of the contact wire and the messenger wire
K_{ed}	element stiffness matrix of the dropper
K_{eb}	element stiffness matrix of the moving bracket
K_{ea}	element stiffness matrix of the steady arm
K	overall stiffness matrix of the catenary
$\underline{d}$	displacement vector of the contact wire
$\underline{f}$	force vector on the contact wire
$\underline{k}$	stiffness vector of the catenary
x	horizontal position in the catenary span

characteristics and the decreasing width of dynamic variation are needed. Progress has been made in recent research assuring the ability of high-speed driving as the basic technology of a high-speed railway [2]. The dynamic interaction of catenary and pantograph systems has been investigated extensively. Ockendon and Taylor [3] described an approximate analytical formulation to determine contact force between a contact wire and a pantograph. Manabe [4] conducted research on wave analyses to study the response between the pantograph and the catenary with discrete support springs. Wu and Brennan [5] investigated the dynamic relation between the catenary and the pantograph using finite element method (FEM). Vinayagalingam [6] studied contact force variation and pan-head trajectory by using finite difference methods. Today's situation is that an active pantograph is proposed for more stable current collection through maximizing the ability of the pantograph to follow the catenary [7–9].

To improve the performance of the pantograph, its dynamics should be considered more precisely before applying an active system. Especially, many researchers trying to improve the system performance, have suggested using sensitivity analysis as an efficient tool for checking variations in design variables based on its dynamics. Vanderplaats and Arora [10,11] found that sensitivity information can be used as a design basis when re-designing a system. Haug et al. [3] investigated dynamic sensitivity analysis which is utilized for variation evaluation of mechanisms in the dynamic state. Jang and Han [12] devised a way to conduct dynamic sensitivity analysis for studying state sensitivity information with respect to changes in design variables. Sensitivity analysis about the pantograph system can be a useful tool to improve dynamic characteristics of a pantograph.

In this study, the dynamic characteristics of a catenary system and pantograph supplying electrical power to high-speed trains are investigated. The analytical model of a catenary and a pantograph is composed to simulate the behavior of an actual system. To obtain the model of the catenary system for high-speed operation, we perform the analysis of the catenary system using FEM. The pantograph system is assumed to be a 3dof model using lumped parameters. The reliability of the dynamic model is verified by the comparison of the excitation test with fast Fourier transform (FFT) of the actual system. State sensitivity analysis was executed with respect to design variables of the pantograph system. Uplift force increased by aerodynamic lift force affects displacement and contact forces occurring in between the catenary and the pantograph system directly. Therefore, the lift force data acquired from experiments are utilized for sensitivity analysis. From