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Dynamic sensitivity analysis for the pantograph of a high-speed rail vehicle

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Abstract

In this study, the dynamic characteristics of a catenary system using the finite element method (FEM) and dynamic modelling for developing a suitable pantograph at high speed is analyzed. First, the catenary system of a high-speed railway is assumed to be a beam model. Next, an analysis program using finite element analysis was performed. The pantograph of linear spring–mass system is assumed to be three-degrees-of-freedom model for the finite element analysis. The analyses of the catenary based on the FEM are executed to develop a pantograph that meets the necessary standards for high-speed rail vehicles. Using a simulation of the pantograph–catenary system, the static deflection of the catenary, the stiffness variation in the contact lines, the dynamic response of the catenary undergoing a constant moving load and the contact force analysis were executed. From the pantograph–catenary analysis, the design parameters of a pantograph could be optimized. Based on the design-parameter analysis, a pantograph with improved parameters was found to be suitable for a high-speed rail vehicle.

1. Introduction

At present, the high-speed railway that is focused on as the next generation transportation system is characterized by high stability, high driving velocity and comfort, all of which are uncommon foci of 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. If the railway speed is increased, the width of the catenary's dynamical variation will increase. Contact

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loss will then occur between the pantograph and the catenary. In addition, wear on the pantograph is going to grow as electrical shock and damage occur [11]. Therefore, research for understanding the current-collecting system's dynamic characteristics and the decreasing width of dynamic variation are needed. Progress has been made in research for assuring the ability of high-speed driving as basic technology of a high-speed railway [3,9]. Ockendon and Taylor described an approximate analytical formulation to determine contact force [12]. Manabe conducted research on wave analyses to study the response between the pantograph and the catenary with discrete support springs [6]. Wu and Brennan investigated the dynamic relation using the finite element method (FEM) between the catenary and the pantograph [7]. Vinayagalingam studied contact force variation and panhead trajectory by using finite difference methods [10]. 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 [2–5].

To improve the performance of the pantograph, its dynamics should be more considered before applying active system. Especially, many researchers for improving the system performance have been suggested using sensitivity analysis as an efficient tool for checking variations in design variables based on its dynamics. Vanderplaats and Arora found that sensitivity information can be used as a design basis when re-designing a system [13,14]. Haug et al. investigated dynamic sensitivity analysis, which is utilized for variation evaluation of mechanisms in the dynamic state [12]. Jang and Han devised a way to conduct dynamic sensitivity analyses for studying state sensitivity information with respect to changes in design variables [1]. Therefore, sensitivity analysis is useful tool for improving dynamic characteristics of a pantograph.

The output of the pantograph system analyzed by catenary dynamics and pantograph dynamics is contact force between catenary and pantograph as the ability of the stable current collection of the pantograph can be determined by contact force. The objective of this research is to study state sensitivity information for contact force with respect to changes in the design variables on pantograph.

In this study, the catenary system of a high-speed railway was assumed to be a beam model. Using FEM for analyzing a high-speed rail pantograph the catenary dynamics is organized for a total of 10 spans and analyzed for confirming contact force more than 350 km/h. The pantograph of a linear spring–mass system is assumed to be a three-degrees-of-freedom model (t.d.o.f.) model. In sensitivity analysis, the direct differentiation method is used. Finally, the dominant design variables of the system are suggested via analysis and trends for the redesign of the pantograph are proposed.

2. Modelling of the catenary and the pantograph

Three types of centenary systems can be used in a high-speed railway—simple, stitched and compound. The reason for having various types of catenaries is to unify the mechanical characteristics of the contact wire contacting the pantograph.

2.1. Modelling of the catenary system

Fig. 1 shows the structure of a simple catenary system.