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Substructure synthesis method for a nonlinear structure with a sliding mode condition

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Abstract

The component mode synthesis (CMS) method is widely used to establish reduced dynamic models of complex structures so that iterative problems such as flutter analyses can be efficiently analyzed with reasonable cost and time. In the present study, a structural coupling method is developed for the dynamic analysis of a nonlinear structure consisting of substructures connected by nonlinear interfaces such as nonlinear hinge joints or sliding mode conditions. In order to verify the coupling method extended to consider the hinge joints, a numerical plate model consisting of two substructures and torsional springs is synthesized, and its modal parameters are compared with analysis data. The extended coupling method is further improved to consider the sliding mode condition. The improved coupling method is applied to a three-substructure-model with nonlinearity of sliding lines between the substructures. Finally, using the proposed coupling method, a dynamic model of a tilting structure consisting of two substructures with sliding line conditions is synthesized, and its dynamic characteristics are investigated. The analysis results show that the improved coupling method is effectively applicable to the dynamic analysis of a nonlinear structure with the sliding mode condition.

1. Introduction

Most practical engineering structures are complicated with distributed or concentrated structural nonlinearities. For example, a deployable missile control fin has a nonlinear hinge joint that consists of a torsional spring, a compression spring, and several stoppers. Because of wear and manufacturing tolerance, the hinge has some structural nonlinearities such as preload, free-play, asymmetric bilinear stiffness, hysterisis, and coulomb damping [1]. Another example is a pantograph tilting system consisting of a pantograph and a tilting structure. The pantograph tilting system is currently being used in tilting trains, which are becoming the standard internationally, especially in Europe. The car body of a tilting train moving on a curved line is tilted inward to compensate the centrifugal force, as shown in Fig. 1. Therefore, the speed and run can be increased

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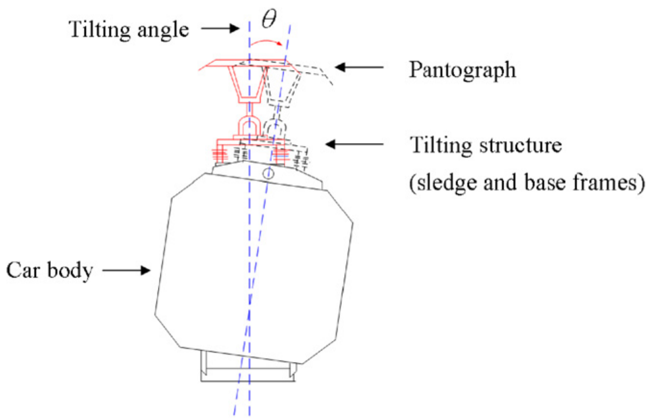

Fig. 1. Schematic diagram of pantograph tilting structure.

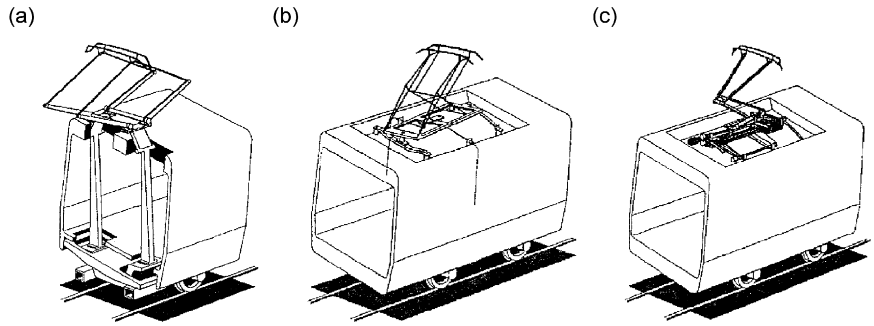

Fig. 2. Pantograph tilting devices: (a) bogie mounted pantograph; (b) roof mounted passive pantograph; and (c) roof mounted active pantograph [2].

on conventional curved lines whereas normally speed reduction would be necessary. In order to maintain a reliable electrical energy supply from the catenary to the train by means of the contact between the pantograph and catenary cables, even when the train is at maximum inclination, the train must have an anti-tilt mechanism such as a bogie mounted pantograph or roof mounted passive or active pantographs, as shown in Fig. 2. The roof mounted active tilting structure, which consists of base and sledge frames driven by electromechanical actuators, has been widely used and developed. Despite disadvantages such as more complex failure modes and new design, this structure allows for no loss of passenger seats and full compensation of the suspension roll effect while being of low weight [2]. The pantograph tilting systems also have some structural nonlinearities because of worn or loose hinges of the pantograph, and a sliding mode condition between the sledge and base frames. These nonlinearities cannot be completely eliminated, and exert significant effects on the static and dynamic characteristics of the pantograph tilting structure. Therefore, it is necessary to establish an accurate structural dynamic model to predict or control the nonlinear dynamic systems. However, considerable computational effort is required to perform dynamic analyses of many practical engineering problems by making use of full-order nonlinear finite element models, especially when iterate analyses are required such as time-domain nonlinear flutter analyses or structural optimal design.

In general, most practical engineering structures are complicated and may have some nonlinearities. The information about the position of structural nonlinearity offers opportunities to separate the total structure into linear and nonlinear components, so that they can be analyzed and designed independently. In order to reduce the number of coordinates in a dynamic analysis of a complex structure, the component mode synthesis (CMS) techniques are popularly used in structural dynamic applications for combining substructures or components represented with reduced degrees of freedom (dof). Numerous studies on substructure synthesis methods have been reported. Hunn [3] introduced the first partial modal coupling method. Hurty [4] assumed