Commun Nonlinear Sci Numer Simulat 19 (2014) 3901–3912

Contents lists available at ScienceDirect

Commun Nonlinear Sci Numer Simulat

journal homepage: www.elsevier.com/locate/cnsns

Control of an extending nonlinear elastic cable with an active vibration control strategy

L. Dai *, L. Sun, C. Chen

Sino-Canada Research Centre for Noise and Vibration Control, University of Regina, Canada

ARTICLE INFO

Article history:
Received 27 January 2014
Received in revised form 28 March 2014
Accepted 31 March 2014
Available online 8 April 2014

Keywords:
Nonlinear elastic cable
Active control strategy
Multi-dimensional dynamic system
Multi-dimensional control
Cable controlling

ABSTRACT

An active control strategy based on the fuzzy sliding mode control (FSMC) is developed in this research for controlling the large-amplitude vibrations of an extending nonlinear elastic cable. The geometric nonlinearity of the cable and the fixed–fixed boundary of the cable are considered. For effectively and accurately control the motion of the cable with the active control strategy developed, the governing equation of the elastic cable is established and transformed into a multi-dimensional dynamic system with the 3rd order Galerkin method. The active control strategy is developed on the basis of the dynamic system, and the control strategy is applicable to multi-dimensional dynamic systems. In the numerical simulation, large-amplitude vibrations of the cable are effectively controlled with the control strategy. The results of the research demonstrate significances for controlling the cable vibrations of an elevator in practice.

1. Introduction

The investigations on axially translating structures, such as axially moving beam [1], plate [2], and cable [3], have been conducted extensively in the last several decades. The axially translating structures can be generally divided into two classes depending on whether or not the dimension along the translating direction is variable. Corresponding to designing the aerospace and aeronautical structures, an axially traveling plate, of which the length along the traveling direction is a constant, were investigated [2]. In the study, the analytical solutions of high-speed traveling plates, as well as the buckling stability, have been derived. In addition to axially moving plates, axially moving beam, of which the length is invariant, has drawn scholars' attention as well. For the applications [4], in which the effects of shear deformations cannot be neglected, an axially moving Timoshenko beam was introduced [5]. In the study, a 20-dimension nonlinear dynamic system of Timoshenko beams with invariant length, has been derived, and bifurcations as well as chaos have been discovered from the established system. The class of the axially moving structures with varying length, has also been investigated wildly for its various applications in areas of engineering. Coming from the dynamics of spacecraft antenna, of which the length is varying with time, the equation of motion of a cantilevered beam was established [1]. In the study, a 16-dimension system of the beam has been derived, and a decreasing frequency has been discovered with respect to the increasing length of the beam. Corresponding to hydraulic and motor driven systems, four nonlinear axially moving cantilevered beam models considering a tip mass have been derived, including Timoshenko, Euler, simple-flexible and rigid-body beam models [6]. In the model establishment of the study, it is pointed out the rigid-body motion and the flexible vibration of the beam are nonlinearly coupled and there

* Corresponding author. Address: University of Regina, Regina, SK S4S 0A2, Canada. Tel.: +1 306 585 4498.
E-mail address: liming.dai@uregina.ca (L. Dai).

http://dx.doi.org/10.1016/j.cnsns.2014.03.034
1007-5704/

exists Coriolis forces in the system. Motivated with the application of axially translating media in elevator, the linear dynamics of the class of arbitrary varying length cable with a tip mass was investigated [7]. A 5-dimension system has been derived for the investigation of the energetics and stability of the cable. In the quest for understanding the fluid–structure interactions, a cylindrical cantilevered beam axially immersing in fluid was investigated [8]. A 4-dimension system has been derived and it is reported the system presents a phase of decaying oscillation with increasing amplitude and decreasing frequency. With the interests in self-spinning tethered satellites, an Euler–Bernoulli beam was adopted to represent a tether with varying length [3]. The deployment process of two-self spinning tethered satellite systems have been successfully simulated through a newly proposed hybrid Eulerian and Lagrangian frame work. From the previous works on the dynamics of axially translating structures, a multi-dimensional system is usually preferred [1,5,7,8] in approximating the transverse displacement of the structures, and an increasing-amplitude vibration has been reported in the case of beams and strings with varying length [7,8].

Corresponding to the large-amplitude vibration discovered in various dynamic system, a number of control methods have been proposed. A methodology, the sliding modes control (SMC), was proposed for nonlinear vibration systems [9]. Corresponding to the nonlinear dynamic systems, in which external uncertainties may exist, a control strategy based on SMC, was developed through the application of fuzzy logic theories and hence named as fuzzy sliding mode control (FSMC). FSMC has been applied for controlling the nonlinear vibrations existing in engineering systems, and its applicability has been demonstrated in nonlinear vibration controls [10–12]. Although the FSMC strategy has been successfully employed in controlling the chaotic response of a micro-electro mechanical system (MEMS) [13], from the available literatures it can be found that the established FSMC strategy is merely applicable for the dynamical system, which is derived through the 1st-order Galerkin method.

In the present research, an active vibration control strategy based on FSMC strategy is to be developed for controlling the large-amplitude vibration, which is discovered from a multi-dimensional dynamic system of an extending nonlinear elastic cable. The equations of motion of the cable with fixed–fixed boundary are to be established based on von Karman-type equations and the consideration of the cable's geometric nonlinearity. In developing the solutions of the extending cable, the equations in the forms of partial differential equations are non-dimensionalized and then converted into a multi-dimensional system through the 3rd-order Galerkin method. With respect to the derived multi-dimensional dynamic system, an active control strategy is to be developed based on the FSMC strategy. The applicability and efficiency of the proposed control strategy developed is significant in controlling the nonlinear vibrations of the elastic cable. A case of large-amplitude vibration of the extending nonlinear elastic cable is presented to show the effectiveness of the proposed control strategy in controlling such vibration of the cable.

2. Equations of motion

The extending nonlinear elastic cable investigated in this research is sketched in Fig. 1. The governing equations of motion of the cable are to be derived based on the Hamilton's principle. As can be seen from Fig. 1, the cable is placed between two

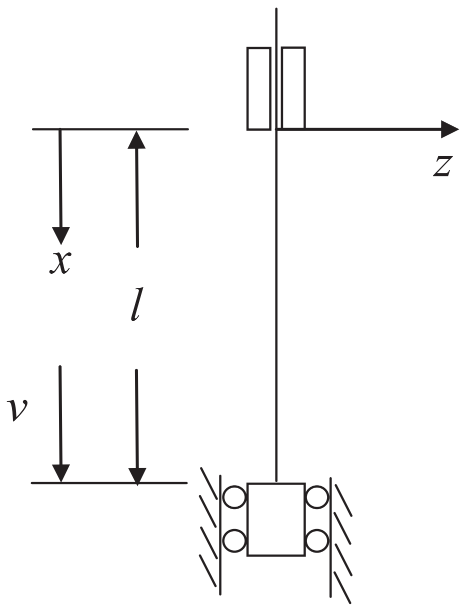

Fig. 1. The sketch of the extending nonlinear elastic cable.