Mechanical Systems and Signal Processing 114 (2019) 68–83

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

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

Synchronous control of two counter-rotating eccentric rotors in nonlinear coupling vibration system

Zhilong Huang, Guiqiu Song *, Yiming Li, Mengnan Sun

School of Mechanical Engineering & Automation, Northeastern University, 110819 China

ARTICLE INFO

Article history:
Received 9 March 2018
Received in revised form 23 April 2018
Accepted 2 May 2018

Keywords:
Nonlinear vibrating system
Phase and speed synchronization
Cross-coupling control
Adaptive global sliding mode control
Stability

ABSTRACT

In this paper, the problem of speed and phase synchronization control of two eccentric rotors (ERs) driven by asynchronous motors in a nonlinear vibration system (NVS) with nonlinear time-varying load torque is investigated. The electromechanical dynamic coupling model of NVS is established, in which the complex control of the electromechanical coupling model converts to speed and phase synchronization control of two ERs. A precise control method of speed and phase synchronization of ERs for NVS is proposed. Design the speed and phase synchronization controller by cross-coupling control (CCC) strategy and adaptive global sliding mode control (AGSMC) algorithm. The controller stability is verified by Lyapunov theorem and Barbalat lemma. The performance of the proposed control system is proved by simulation analysis and compared with the traditional self-synchronization method. The results show that the proposed control system considering the cross-coupling characteristics of ERs can effectively control the speed and phase synchronization of two ERs in NVS. The proposed control method can reduce the chattering clearly and improve the control precision. The influence of the nonlinear force of the material on the vibration system is analyzed. The influence of reference speed and parameter perturbation on the synchronization performance is discussed, and the proposed controller is proved with strong robustness. The proposed control system considering the cross-coupling characteristics of ERs can make the NVS implement stable linear vibration locus in the working direction.

1. Introduction

Vibration machines can be used to perform screening, separating, dehydrating, transmitting information and so on [1,2]. Slepyan et al. [3] studied parametric resonance mode in a vibrating system. Firstly, the application of synchronization theory in mechanical system is investigated [4]. With the development of self-synchronization methods, the self-synchronization theory excited by two eccentric rotors (ERs) in a vibrating system is gradually applied [5]. In the self-synchronization system, the excitation of two eccentric rotors with dry friction are investigated, relevant experimental verification and numerical simulation is performed [6]. Two asynchronous motors drive the ERs self-synchronizing in the vibration system, which is implemented through the coupling dynamic characteristics of ERs. Because synchronization and stability conditions must be satisfied [7–9], which confine the development of vibration system.

* Corresponding author.
E-mail address: songguiqiusci@126.com (G. Song).

https://doi.org/10.1016/j.ymssp.2018.05.006
0888-3270/

To improve the synchronization control precision, cross-coupling control (CCC) has been extensively applied in synchronization control [10–13]. Deng et al. [14] established two nonlinear coupled synchronous motors mathematical models to improve the synchronization state of the controller by controlling the current and position of the synchronous motor. Zhao et al. [15] used adjacent cross-coupling control for real-time speed synchronous control of multiple asynchronous motors, the simulation validates the effectiveness of the controller when the load changes. Cheng et al. [16] considered the cross-coupling effect between multiple axes, the tracking and synchronization error control is achieved through adaptive robust control under the condition of system uncertainty, and the tracking accuracy of the system is verified by experiments. Sun [17] studied the position synchronization of multi-motion axis by combining CCC. The solution for the contour tracking problem is shown in [18,19]. Chin et al. [20] designed Fuzzy-logic controller to reduce either position error or contour error. Using model-free CCC strategy for multi-axis position synchronization has been investigated [21]. Due to the coupling dynamic characteristics of the vibration system, the synchronous control of two asynchronous motors should consider the cross-coupling characteristics. From above researches, CCC of the speed and phase synchronous motion of two asynchronous motors in a vibration system is investigated scarcely.

Many researchers used sliding mode control (SMC) to promote the robustness of the system [22–24]. To deal with the robustness problem in the reaching phase of SMC, this paper uses adaptive global sliding mode control (AGSMC) to obtain robustness through the whole process [25–27]. Nonlinearity has an important influence in vibration system, the nonlinear vibration and nonlinear coupled systems have been investigated in many papers [28–32]. Kong et al. [33,34] synchronous motion control of the linear vibration system is achieved through master–slave control and composite control. However, the vibrating body in the vibration system is subjected to inertial force, friction force and impact force of material [1,5]. To deal with accurately analyze the vibration system, the nonlinear force of the material should be considered. From above researches, the speed and phase synchronous motion of two asynchronous motors in NVS is investigated scarcely.

In this paper, the speed and phase synchronization analysis and control of two counter-rotating ERs in a NVS are investigated, and the synchronous control is implemented by CCC strategy and AGSMC algorithm. In Section 2, electro-mechanical coupling dynamic model of a nonlinear vibrating system is investigated. In NVS, the investigation of the complex system converts to the motion synchronization of two counter-rotating ERs. In Section 3, the CCC strategy of speed and phase synchronization in NVS is analyzed. In Section 4, synchronization control is achieved by the proposed controller. The stability of the control system is verified. In Section 5, the synchronization performance of proposed controller and the advantages of CCC for synchronization control in NVS are verified. By changing the speed and parameter perturbation, the dynamic response of the NVS is presented. Conclusions in this article are presented in Section 6.

2. Electromechanical coupling model of NVS

Fig. 1 shows the electromechanical coupling dynamic model of NVS. Two identical asynchronous motor composition NVS exciters, The two exciters are symmetrically installed and revolve in the opposite directions. *oxy* coordinate is taken in the centroid of the system, the vibrating body is supported by symmetrically installed springs. NVS is divided into *x*, *y* direction of the vibration and swinging around centroid ψ. When speed and phase of two exciters are the same respectively, NVS can only vibrate in the *y* axis, and eliminates lateral movement in the *x* direction and swing motion in the ψ direction. Take angle δ as the working angle. The motion of material in the vibration system is usually throwing motion, in the establishment of the vibration equation, the non-linear force of the material must be considered, F_{mx} and F_{my} are the nonlinear forces acting on the vibrating body by the material in the x and y directions.

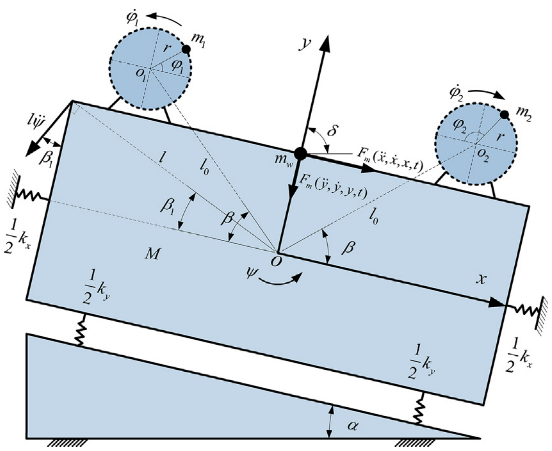

Fig. 1. Electromechanical coupling dynamic model of a NVS.