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Phase and speed synchronization control of four eccentric rotors driven by induction motors in a linear vibratory feeder with unknown time-varying load torques using adaptive sliding mode control algorithm

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ABSTRACT

In this paper, phase and speed synchronization control of four eccentric rotors (ERs) driven by induction motors in a linear vibratory feeder with unknown time-varying load torques is studied. Firstly, the electromechanical coupling model of the linear vibratory feeder is established by associating induction motor's model with the dynamic model of the system, which is a typical under actuated model. According to the characteristics of the linear vibratory feeder, the complex control problem of the under actuated electro-mechanical coupling model converts to phase and speed synchronization control of four ERs. In order to keep the four ERs operating synchronously with zero phase differences, phase and speed synchronization controllers are designed by employing adaptive sliding mode control (ASMC) algorithm via a modified master-slave structure. The stability of the controllers is proved by Lyapunov stability theorem. The proposed controllers are verified by simulation via Matlab/Simulink program and compared with the conventional sliding mode control (SMC) algorithm. The results show the proposed controllers can reject the time-varying load torques effectively and four ERs can operate synchronously with zero phase differences. Moreover, the control performance is better than the conventional SMC algorithm and the chattering phenomenon is attenuated. Furthermore, the effects of reference speed and parametric perturbations are discussed to show the strong robustness of the proposed controllers. Finally, experiments on a simple vibratory test bench are operated by using the proposed controllers and without control, respectively, to validate the effectiveness of the proposed controllers further.

1. Introduction

Linear vibratory feeder is often used for conveying and feeding small engineering parts in modern automatic assembly systems [1,2] and granular material in food, manufacturing and mining industries [3–6]. A horizontal or near-horizontal conveying surface vibrates in the sloped direction called the vibration direction. Hence, there is an in-plane and a normal component of vibration. The small parts or granular material can move toward the conveying direction. In a type of linear

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vibratory feeders, two eccentric rotors (ERs) rotating synchronously with zero phase difference in the opposite direction are chosen as exciters to provide the excitation force in the vibration direction. Blekhman [7,8] firstly proposed the self-synchronization theory of two ERs. Moreover, self-synchronization theory and technology were applied to replace the forced synchronization in many vibratory machines including linear vibratory feeder [9]. In the small size linear vibratory feeder, two ERs driven by low power induction motors separately are installed on the vibration body directly. Therefore, the structure of linear vibratory feeder is simple. However, in the large size linear vibratory feeder, high power induction motors should be installed on the ground driving the ERs indirectly because of their large size. In this case, the structure will change more complex and their applications will cover larger areas. Using more low power induction motors driving more symmetrical ERs installed on the vibration body directly to replace the high ones installed on the ground is a reasonable idea to overcome the shortages. However, with the increase of quantity of ERs, the self-synchronization motion of multiple ERs with zero phase difference is difficult to be implemented or even cannot be implemented in some situations [9,10]. In this work, the problem of synchronization motion of four ERs with zero phase differences is addressed by control technology.

Recently, many synchronization control strategies have been designed for multiple motors or components in various mechanical fields. Deng et al. [11] studied the motion synchronization of two coupling permanent magnet synchronous motors (PMSMs) with nonlinear constraints. To keep the two motors synchronization, the synchronization controller was designed via cross- coupling control structure and interval matrix based on load observer. Cheng et al. [12] investigated the accurate synchronization motion control for multi-axis motion system in manufacturing industry. On the consideration of cross-coupling dynamics among different axes, an adaptive robust control scheme was used to design the compensator for tracking and synchronization. Sencer et al. [13] addressed the problem of motion synchronization in dual spindle servo systems by employing a continuous time SMC. Zhang et al [14] studied the chaotic speed synchronization of multiple induction motors by using the adaptive time-delayed feedback control and the direct torque control (DTC) laws based on the stator flux regulation method. Lin et al. [15] designed a digital signal processor (DSP)-based cross-coupled intelligent complementary SMC system to implement synchronous control of a dual linear motor servo system. In their work, the Takagi-Sugeno-Kang-type fuzzy neural network estimator was implemented to estimate the lumped uncertainty. Chen et al. [16] designed a new cross-coupling synchronous controller by employing an H_∞ control law for position synchronization control of multi-axes. Tomizuka et al. [17] studied the speed synchronization of two DC motors by using adaptive feed-forward control. Zhao et al. [18] investigated the speed synchronization of multiple induction motors by employing SMC law based on adjacent cross-coupling control structure. From above researches, the synchronization motion control of multiple induction motors in the vibration system is studied scarcely.

In the paper, phase and speed synchronization control of four ERs driven by induction motors in a linear vibratory feeder with unknown time-varying load torques is investigated. In Section 2, introducing the model of induction motors, an under actuated electromechanical coupling model of a linear vibratory feeder is developed. According to the characteristics of the linear vibratory feeder, the complex control problem of the under actuated system converts to the phase and speed synchronization control of four ERs. In Section 3, the modified adaptive sliding mode master-slave controllers are designed by introducing the ASMC algorithm to the modified master-slave control structure. Moreover, the stability of the controllers is discussed based on Lyapunov stability theorem. In Section 4, the simulations on Matlab/Simulink are operated to explain the effectiveness of the proposed controllers to reject the time-varying load torques. Moreover, compared with conventional SMC algorithm, the advantages are performed. Additionally, the effects of reference speed and parametric perturbations are discussed. In Section 5, experiments on a simple vibratory test bench are operated by using the proposed controllers and without control, respectively, to further explain the effectiveness of the proposed controllers. Finally, some conclusions are presented in Section 6.

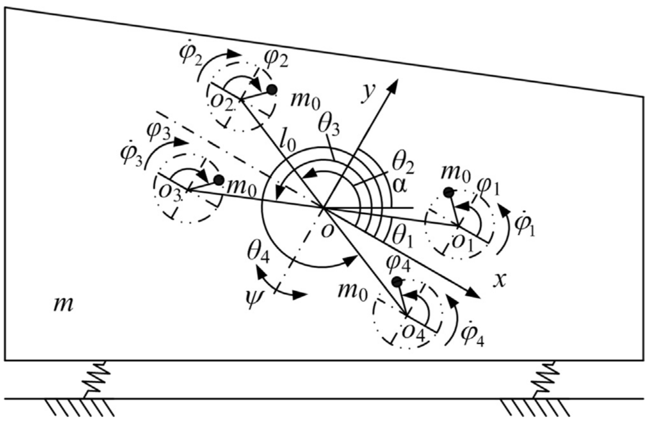

Fig. 1. Dynamic model of a linear vibratory feeder.