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Identification and compensation of friction for a novel two-axis differential micro-feed system

Fuxin Du, Mingyang Zhang, Zhaoguo Wang, Chen Yu, Xianying Feng *, Peigang Li *

School of Mechanical Engineering, Shandong University, Jinan, Shandong 250061, China
Key Laboratory of High Efficiency and Clean Mechanical Manufacture of Ministry of Education, Shandong University, Jinan, Shandong 250061, China

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ABSTRACT

Non-linear friction in a conventional drive feed system (CDFS) feeding at low speed is one of the main factors that lead to the complexity of the feed drive. The CDFS will inevitably enter or approach a non-linear creeping work area at extremely low speed. A novel two-axis differential micro-feed system (TDMS) is developed in this paper to overcome the accuracy limitation of CDFS. A dynamic model of TDMS is first established. Then, a novel all-component friction parameter identification method (ACFPIM) using a genetic algorithm (GA) to identify the friction parameters of a TDMS is introduced. The friction parameters of the ball screw and linear motion guides are identified independently using the method, assuring the accurate modelling of friction force at all components. A proportional-derivate feed drive position controller with an observer-based friction compensator is implemented to achieve an accurate trajectory tracking performance. Finally, comparative experiments demonstrate the effectiveness of the TDMS in inhibiting the disadvantageous influence of non-linear friction and the validity of the proposed identification method for TDMS.

1. Introduction

A feed drive system has become increasingly important in manufacturing, inspection and assembly. However, friction significantly and negatively affects the positioning accuracy of a feed drive system. Accurate and homogeneous displacement is difficult to realise in a typical conventional drive feed system (CDFS) equipped with linear motion (LM) guides and ball screws. Friction between two rolling contact components frequently generates large tracking errors, undesired stick-slip motions and limited cycles [1–5].

A novel dual-drive feed system (TDMS) based on a nut-rotating-type rolling screw transmission pair is proposed to realise high-precision motion control in this study. In TDMS, the screw and nut are both driven by permanent magnet synchronous motors (PMSMs). Superposing the two rotating motions with the same rotating direction and nearly equal in velocity by the dual-drive transmission structure, the driven table could obtain high-precision micro-feed under ultra-low speed. The non-linear disturbance from the ball screw can be reduced significantly compared with a CDFS, because the screw and nut both rotate at high speed. Note that, the non-linear friction disturbance of the LM guides and the linear friction of ball screw

* Corresponding authors at: No 17923, Jingshi Road, School of Mechanical Engineering, Shandong University, Jinan 250061, Shandong Province, PR China.
E-mail addresses: dufuxin@sdu.edu.cn (F. Du), 1093740237@qq.com (M. Zhang), 1027262765@qq.com (Z. Wang), yuchen7701@foxmail.com (C. Yu), fxying@sdu.edu.cn (X. Feng), pgli@vip.sina.com (P. Li).

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remains. Therefore, friction compensation techniques should be proposed to achieve higher precision in the position control of a TDMS.

Friction modeling and compensation have attracted much interest for decades. Physically or empirically motivated models combined with efficient identification method based on experimental data are used to compensate friction. Numerous friction models have been reported to describe friction [6–8]. Both sliding and pre-sliding frictions are successfully incorporated in the LuGre model proposed by de Wit et al. [9]. In particular cases, it can turn to be many friction models, such as Coulomb, Stribeck and Dahl models. Some more advanced models are proposed in the literature [10–12] to reduce the LuGre model limit, but taking into account the simplicity of the model requires less parameters, we will only consider LuGre model in this paper [13]. Sun [14] presents a comprehensive experimental setup that can be used to identify the parameters of selected friction models. Kim [15] proposes a method to investigate friction using a ball-screw driven servomechanism in the frequency domain, in which friction elements are estimated through the limit cycle analysis in a velocity control loop. Liu [16] introduces a comprehensive parameter identification method to identify the friction parameters of feed servo systems. Based on the stick-slip response of a worktable, the Stribeck friction parameters are obtained using the direct graphical registration method. However, in these studies, the friction characteristics of ball screws and LM guides in CDFS are considered to be the same. In addition, friction models are all built as dynamic functions of the velocity of only one component, because the velocity of the other component can be obtained by multiplying the transmission ratio [17].

A certain ultra-low velocity of the table in TDMS, however, can be obtained by selecting different combinations of macro velocities. Conventional friction parameter identification method (CFPIM), which considers the friction characteristics of ball screw and LM guide similar to those in TDMS, is impossible to use.

This paper introduces a novel all-component friction parameter identification method (ACFPIM) to identify the friction parameters of TDMS. The friction parameters of the ball screw and LM guide are identified individually by this system. The proposed method is advantageous because the friction model can be identified easily without using force sensor as shown by the special structure of the TDMS. The rest of this paper is organised as follows. The structure of the TDMS and friction analysis are described in Section 2. Identification algorithm and strategy of ACFPIM are explained in Section 3. The design of the friction compensation controller is discussed in Section 4. The results of the experiment are then analysed in Section 5. Finally, conclusions are drawn in Section 6.

2. Description and modeling of system

2.1. System description

The block diagram of the adopted dual-drive feed system is shown in Fig. 1. The drive feed table is equipped with a nut-rotating-type ball screw and a set of LM guides. A nut-rotating-type ball-screw with large size balls is chosen for the mechanism to eliminate the axial clearance of the ball-screw transmission and improve axial rigidity. The screw is driven by a

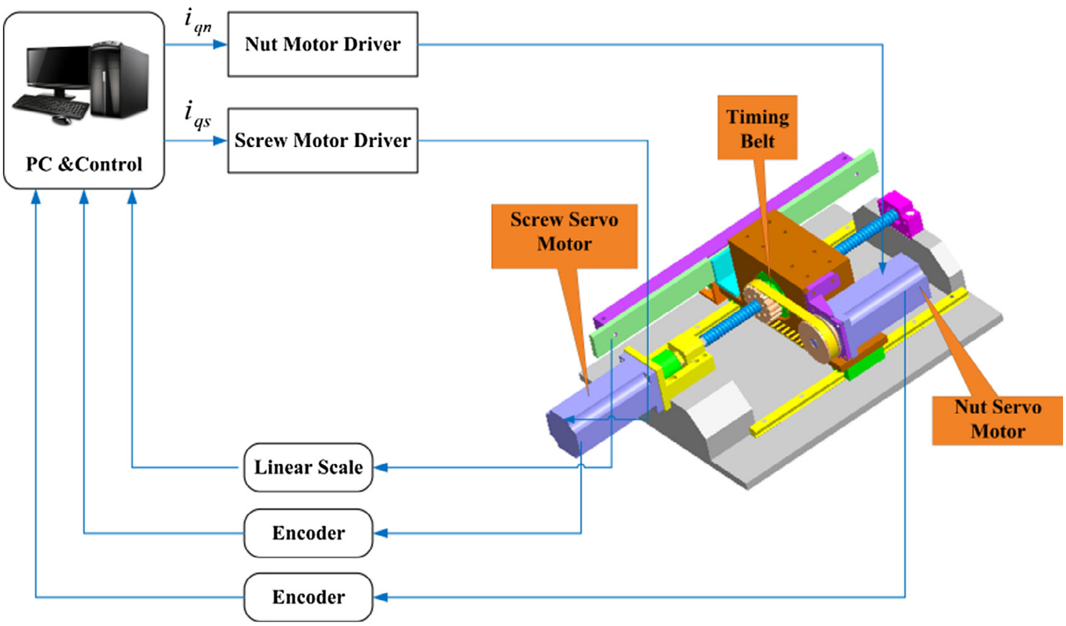

Fig. 1. Block diagram of the dual-drive feed system.