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Comprehensive parameter identification of feed servo systems with friction based on responses of the worktable

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ABSTRACT

A comprehensive identification method for structure and friction parameters of feed servo systems is put forward. A motor direct-connected feed system with Stribeck friction law is investigated. The relation between the critical stick-slip velocity of the worktable and the structure parameters as well as the difference between the static and Coulomb friction coefficient is derived first. Then, according to the data of critical stick-slip velocities at different feed positions, the structural parameters (such as diameter, lead and bearing length of the ball screw) are estimated using the nonlinear least square method. Furthermore, based on the stick-slip displacement response of the worktable, the Stribeck friction parameters are obtained using the direct graphical registration method. The feasibility and validity of the presented identification method is verified by numerical simulation. All the work can provide a theoretical reference for the comprehensive parameters identification of feed systems.

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1. Introduction

The feed system with a motor direct-connected ballscrew has become a main component in many high precision CNC machine tools. Accurate estimation of structure and friction parameters is necessary for determining the control laws best suited for the active control strategy. In the aspect of structure parameters identification, the frequency domain methods are often used, where both input and output measurements are used to set up a transfer function of the system for identification.

The friction between the guide way and the worktable has been the major element that affects the dynamic performance of the feed system at low velocity. Friction degrades the positioning accuracy and usually leads to tracking error, stick-slip motion and limit cycle oscillation [1]. In order to improve the dynamic performance of the feed system, a lot of research works have been done [2–4]. The Stribeck model has been used more often in recent years because of its simplicity of expression and application. The static map of the friction force and velocity is often used for friction identification in the time domain methods. Canudas-de-Wit and Lischinsky [5] identified the Stribeck parameters by using the nonlinear least square method according to the measured curve of the velocity versus friction force. Lorinc et al [6] first approximated the Stribeck curve by means of piecewise linearization, and then identified the Stribeck parameters based on the static map curve of the velocity versus friction force. Guo et al [7] put forward a non-eversible friction model, in which the Stribeck parameters are also identified from the static map. The frequency domain methods are usually based on describing function approximation and limit cycle analysis. Kim and Chung [8] linearized the nonlinear Stribeck friction model, and the static,

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Coulomb and Stribeck velocity parameters are identified by using the harmonic balance method and the describing function approximation. But in his method, two sets of biased torque input and velocity output signals are needed.

This paper put forward a comprehensive method for both structure and friction parameters identification of feed servo systems, which only needs the output responses of the worktable. The feed system is simplified into a classic single degree of freedom (SDOF) mechanical system. According to the critical stick-slip velocity of the worktable, the structure parameters can be identified using the nonlinear least square method. And through the stick-slip displacement of the worktable, the friction parameters can be estimated by the direct graphical registration method. The next is organized as follows. In Section 2, the SDOF mechanical model and the mathematical expression of the motor direct-connected feed system is given, and the static+Coulomb and Stribeck friction models are presented. In Section 3, the nonlinear function relation between the critical stick-slip velocity and structural parameters is achieved. The nonlinear least square method is adopted to identify the structural parameters. And In Section 4, the identification method of the Stribeck friction parameters using the direct graphical registration method is illustrated. Numerical simulations are presented to illustrate the validity of the proposed method in Section 5. Conclusions are drawn in Section 6.

2. System description and modeling

The general structure of a motor direct-connected feed system is shown in Fig. 1. It mainly consists of servo motor, coupling, ballscrew assembly, worktable, bearings and guide way. The rotary motion of the servo motor is transferred into linear motion of the worktable by means of the ballscrew assembly.

In order to analyze expediently, the feed system shown in Fig. 1 is simplified into a SDOF system shown in Fig. 2. Some assumptions made in the procedure of modeling are (1) comparing with the mass of the worktable, the mass of the nut and the coupling is ignored, (2) the torsional deformation of the coupling is ignored, and (3) the axial stiffnesses of the bearing and the nut are considered as rigid.

According to the model in Fig. 2, the governing equation of the SDOF system is

$$M_e\ddot{x}+C_e(\dot{x}-v)+K_e(x-vt)+F_f=0 \tag{1}$$

in which, M_e is the equivalent mass, K_e the equivalent stiffness, $C_e=2\xi\sqrt{K_eM_e}$ the equivalent viscous damping, v the driving velocity, F_f the friction force, and x, $\dot{x}$ and $\ddot{x}$ the displacement, velocity and acceleration of the mass respectively.

2.1. Equivalent mass calculation

According to the kinematic energy equivalent principle of the system, the equivalent mass can be calculated from the rotational inertia of the motor rotor, the coupling, the ballscrew and the worktable, that is

$$M_e=(J_m+J_{bs})(1/r)^2+m \tag{2}$$

in which, m is the mass of worktable, J_m the rotational inertia of the motor rotor, J_c the rotational inertia of the coupling, $r=\lambda/2\pi(m/\text{rad})$ the conversion coefficient of the rotational motion and linear motion, with λ the lead of the ballscrew, and J_{bs} the rotational inertia of the ballscrew which is expressed as

$$J_{bs}=\frac{\rho\pi L(d/2)^4}{2} \tag{3}$$

with ρ is the denisity, L the supporting length of the ballscrew, and d the nominal diameter of the ballscrew.

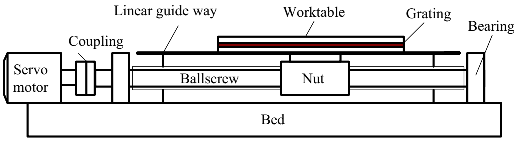

Fig. 1. Schematic of the motor direct-connected feed system.

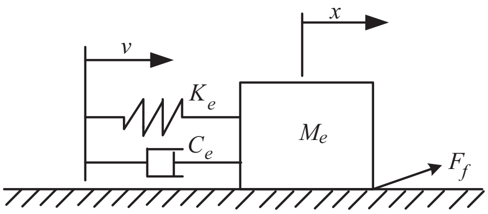

Fig. 2. A simplified SDOF mechanical model.

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